AD-761 812

LONG-TERM BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT VERY LONG PERIOD EXPERIMENT SITES

Stephen A. Alsup, et al

Texas Instruments, Incorporated

Prepared for:

Advanced Research Projects Agency
Air Force Techn.cal Applications Center

21 February 1973

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

AFTAC Project No. VELA T/2705/B/ASD

AD 761 812

LONG-TERM BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT VERY LONG PERIOD EXPERIMENT SITES

SPECIAL REPORT NO. 3
EXTENDED ARRAY EVALUATION PROGRAM

Prepared by
Stephen A. Alsup and Ervin S. Becker

T. W. Harley, Program Manager
Area Code 703, 836-3882 Ext. 300

TEXAS INSTRUMENTS INCORPORATED
Services Group
Post Office Box 5621
Dallas, Texas 75222

Contract No. F33657-72-C-0725
Amount of Contract: $417,000
Beginning 1 April 1972
Ending 31 March 1973

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Order No. 1714
ARPA Program Code No. 2F10

21 February 1973

Acknowledgement: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F33657-72-C-0725.

ABSTRACT

A series of one-hour samples of seismic noise have been taken from vertical instrument channel recordings at the Very Long Period Experiment (VLPE) sites for evaluation of the long-term broau-band earth noise field in the VLPE network. Converted power spectral density estimates of the root-mean-square (RMS) noise amplitudes in the samples were corrected for channel response characteristics and then examined for long term trends and both broad and narrow band variability. Correlation of intraband noise variability is discussed.

Results of the investigation show three general characteristics of the noise field in the 13.5 - 62.5 second band:

(1) A broad "stable minimum" in the noise field in the 30-40 second band is present at all sites when viewed in a long-term sense.

(2) Another possible psuedo stable minimum exists at wave periods less than 15 - 18 seconds.

(3) RMS amplitudes are considerably more variable in the 15 - 20 second band in comparison to the 30 - 40 second band, and very little correlation of narrow band amplitude change is evident over the entire band (a condition which reflects the stability of the noise minimums).

Preceding pagesblank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF TABLES

SECTION I

INTRODUCTION

Several recent reports (Pomeroy, et al. 1969; Murphy, et al, 1972) have identified the presence of a 'stable noise minimum' in the structure of the earth's seismic noise field. This feature has been interpreted in terms of non-propagating motion related to barometric fluctuations acting on the surface of the earth (Capon, 1969; Sorrells and Der, 1970, Sorrells, et al, 1971; Savino and Ryun, 1972) rather than the residual motion of signals initiated by earthquakes or explosions. The presence of the minimum, which usually lies in a band of wave periods of about 30 to 40 seconds, has been demonstrated on the basis of a few samples of 'typical' seismic noise recordings a few hours in length. Since noise minimum offers the possibility of lower amplitude signal detection capability for long-period surface waves which might be obscured in higher microseismic amplitudes in the 15 to 18 second band, it has assumed importance in seismic discrimination problems (Savino, 1970, 1971; Savino, et al, 1972).

The intent of this report is to extend the observational base for delineating the stable minimum at several locations throughout the world in terms of amplitude and bandwidth. We also will show some other important characteristics of earth noise structure in the 13.5 - 62.5 second band which are of some potential interest in signal detection problems and to an understanding of earth noise structure in general.

SECTION II

DATA SOURCES AND ANALYSIS PROCEDURES

Samples of seismic noise were taken from the digital magnetic tape recordings made by the Very Long Period Experiment (VLPE) systems at the locations shown in Figure II-1. The coordinates of the stations, three letter station designators, and number of samples at each are given in Table II-1. Times for sampling extended from parts of August through October of 1971 (Julian Days 230-300), January through March of 1972 (Julian Days 001-080), and June through August of 1972 (Julian Days 150-250). Operational status of the stations and usefulness of the digital recordings for noise analysis varied considerably during these intervals, and all locations were not necessarily represented during any particular time. Sampling density at each location is shown in the analysis results presented in Section III.

For noise analysis, digital recordings of the vertical channel output of about one-hour length (3584 seconds, two seconds per sample) were selected from times free of known seismic signals (usually at the same time for all stations sampled). Time of data sampling was also varied so that representation of the daily variations at each location was obtained. Data which included system malfunctions, local signals, or other known contamination of 'typical' noise characteristics were rejected. Some 604 hours of noise recordings were obtained from the eight stations examined.

Power Spectral Density (PSD) estimates of each one-hour sample were then calculated using the computer facilities at the Seismic Data Analysis Center (SDAC) and the data analysis programs of the VLPE Software Package (Texas Instruments Incorporated, 1971). Resulting PSD were then integrated over narrow bands about 4 millihertz wide (limited to about 13.5 - 62.5 seconds period bandwidth equivalent) and converted to total amplitude

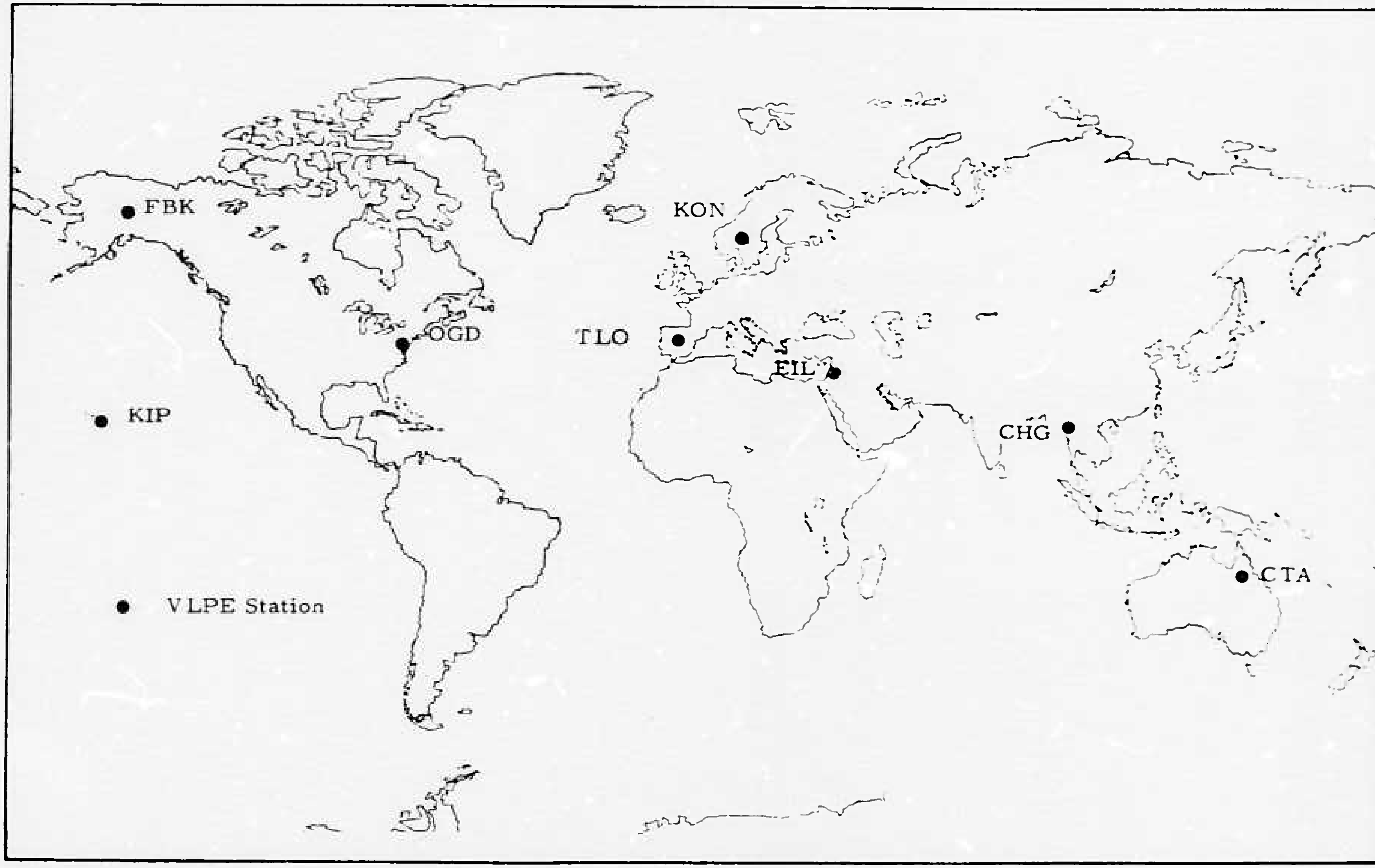


FIGURE II-1

VLPE STATION LOCATIONS

TABLE II-1

VERY LONG PERIOD EXPERIMENT (VLPE) STATIONS AND LOCATIONS

Station	Designator	Latitude	Longitude	Number of Samples
Charters Towers, Australia	CTA	20.1S	146.3E	33
Chaing Mai, Thailand	CHG	18.8N	99.0E	47
Fairbanks, Alaska	FBK	64.9N	148.0W	100
Toledo, Spain	TLO	39.9N	4.0W	100
Eilat, Israel	EIL	29.3N	34.5E	(79)
Kongsvery, Norway	KON	59.6N	9.6E	100
Ogdensburg, New Jersey	OGD	41.1N	74.6W	73
Kipapa, Hawaii	KIP	21.4N	158.0W	72

counts in each narrow band. Some 16 narrow bands were present in the total bandwidth considered. The counts were then corrected for the system amplitude response by applying amplitude correction factors appropriate for the center of each narrow band before further analysis of the noise data.

Total bandwidth discussed here is limited to the 13.5 to 62.5 second range because of potential systematic additive errors related to (1) uncertainties of the stability of system response fall-off rate at shorter periods and (2) to an apparent systematic rise of amplitudes at longer periods. Intermediate bandwidth PSD estimates ranging from 20-40 seconds, 17-25 seconds, and 30-40 seconds bandwidth equivalent were calculated to examine long term trends of the noise field. The intermediate band estimates were also corrected for system amplitude response in each narrow band included within the bandwidths.

System response characteristics used to correct the PSD were obtained from station installation reports or by data provided during communications with John Savino of the Lamont-Doherty Observatory at Palisades New York, and Jon Peterson of the Seismological Center at Albuquerque, New Mexico. One typical vertical channel response is shown in Figure II-2.

The procedures described above provide an estimate of the root-mean-square (RMS) ground motion amplitude at each recording location during the one-hour samples. The results differ from previous examples of the noise field cited in that a longer total time period is included in the analysis and the system reponse has been removed to display the ground motion rather than RMS trace amplitude (Savino, et al, 1972 also shows ground motion spectra). Past experience with the RMS measure indicates that maximum peak-to-peak amplitudes seen on analog recordings are generally a factor of six to seven times the numerical value of the wideband RMS estimates.

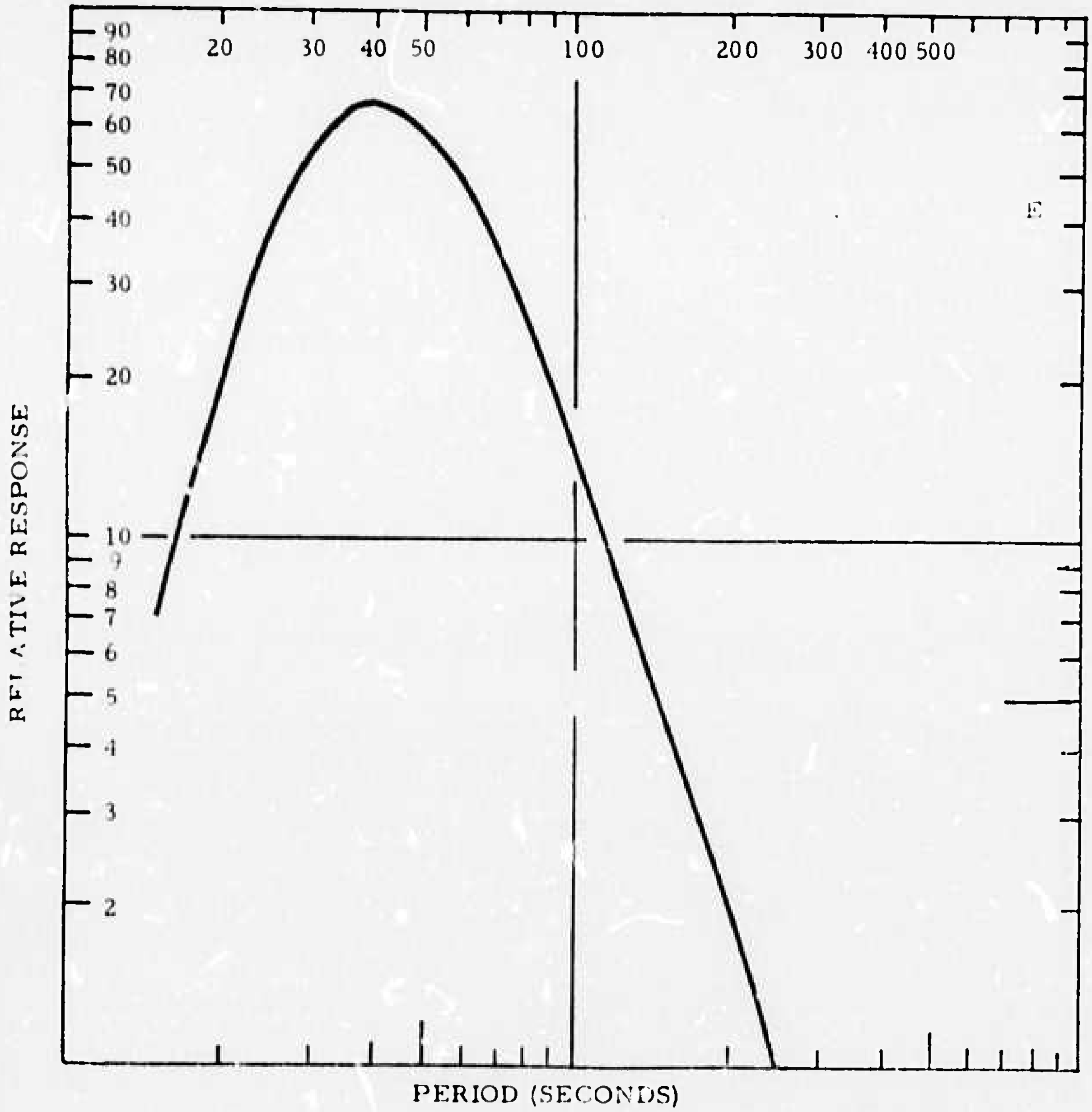


FIGURE II-2

TYPICAL VLPE VERTICAL CHANNEL
SYSTEM RESPONSE

SECTION III
RESULTS

A. GENERAL

The results of the intermediate bandwidth noise analysis will be described in following paragraphs, beginning with 1972 data for the 20-40 second band and followed by 1971-72 data for the 17-25 and 30-40 second band. One sample per day is the maximum number of observations at one station during 1972, but a two sample average for one day is given for some stations during 1971. The 20-40 second band is intended to show the gross trends in RMS noise versus time, while the 17-25 and 30-40 second bands (given on a single plot for each station) are intended to show some contrasts in trend and variability. One-hour RMS noise values are plotted versus the Julian Day of the year when the sample was recorded for the intermediate band data. The vertical axis indicates RMS ground motion amplitude in millimicrons.

More detail of the noise structure is given for the narrow band results, but the variation with time is not given. For the narrow band estimates, the results were analyzed statistically for mean RMS amplitude, standard deviation of each narrow band RMS observation relative to the narrow band mean, and for sample-by-sample intraband correlation to determine if variations in any one narrow band showed a linear relationship with any other band changes. Note that correlation between narrow bands is given here as the coefficient of linear correlation, and not the square of the coefficient.

B. LONG TERM NOISE TRENDS (20-40 SECOND BAND)

Figure III-1 shows the calculated RMS noise amplitude versus Julian Day (1972) in the 20-40 second band. Note that three locations (KON,

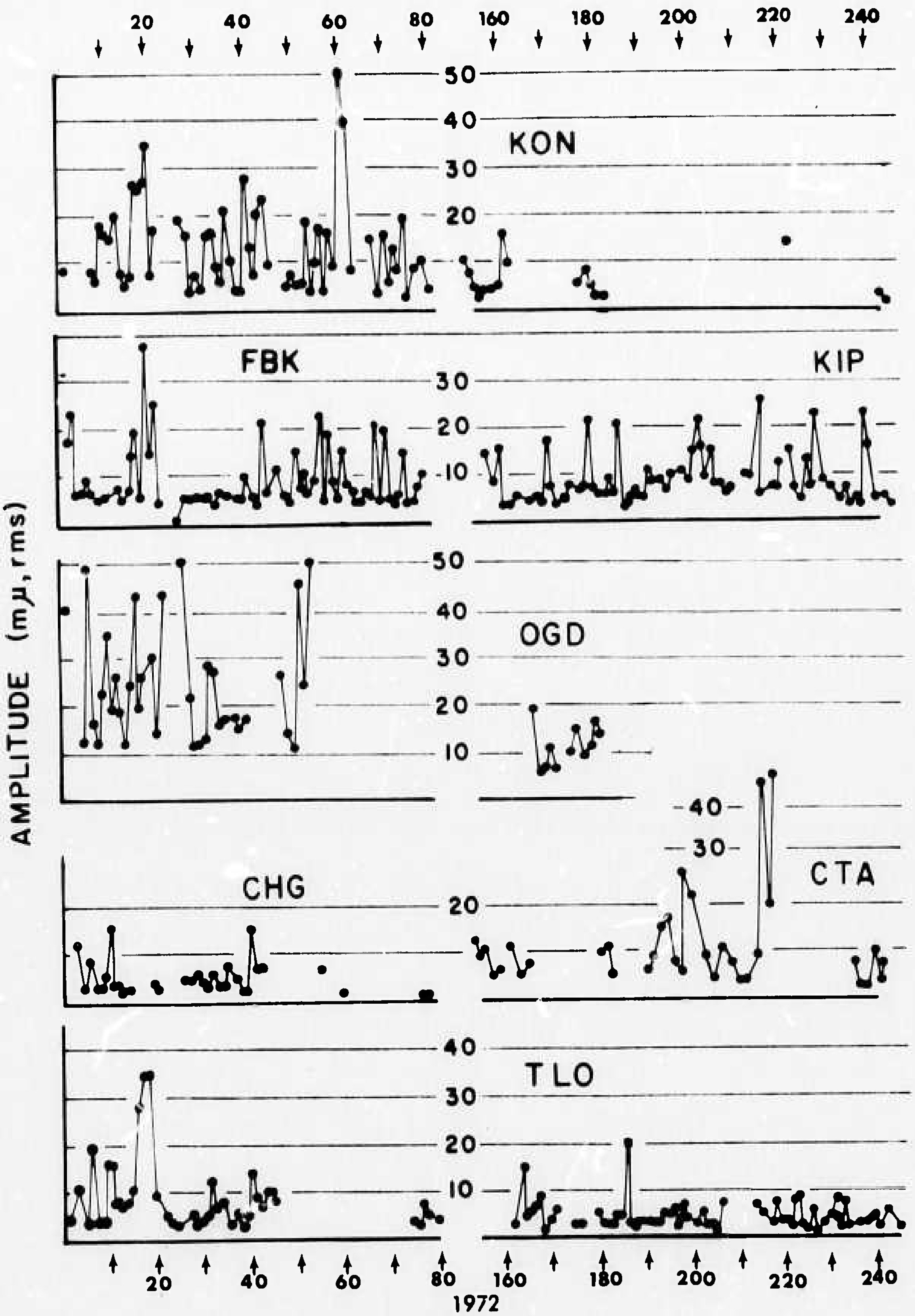


FIGURE III-1

GROUND NOISE AMPLITUDE AT VLPE LOCATIONS 20-40 SECONDS

OGD, and TLO) have data in both early and mid-year sampling intervals. The remaining four locations (FBK, KIP, CHG, and CTA) could be sampled only in one or the other of the two intervals. FBK terminated operations prior to mid-year, KIP provided suitable recordings only in the mid-year interval, CHG data was either unavailable or not readable for the second interval, and CTA experienced operational difficulties with the digital recording system in early 1972. Another station, EIL, recorded data during 1972, but system reliability was questionable.

General characteristics of the intermediate band noise estimates given in Figure III-1 include the suggestion of a slowly changing long term base level of noise at most locations (FBK, KIP, CHG, TLO, and possibly KON, and CTA) which is likely seasonal in nature. A simultaneous noise 'event' of the kind described by Oliver (1962, 1963) and Oliver and Page (1963) is also evident in mid to late January (days 017-020). The RMS noise amplitudes are observed to rise above the base level by factors of four to five over a twenty four hour period and return to the base, and several examples of greater increase in the noise across this band which persists for two or three days are evident. Some periods of five to ten days length with very little change in the RMS estimate are also shown. High average noise levels seem also to be related to times when the noise field is most variable from day to day.

Average RMS noise levels appear to decrease from early 1972 to mid-year at most northern hemisphere stations (KON, OGD, TLO) or remain relatively constant (FBK, KIP, CHG). FBK and KIP show some change over 20-30 day periods in the base level which may be seasonal. Data for CTA (southern hemisphere) are not complete enough to describe a trend realistically, but some increase in the average level is suggested from June to mid-August.

Trends in the base level of the RMS noise might be suspect of representing limits imposed by recording system noise, except that VLPE system noise is at least one order of magnitude lower than the levels shown acorss the bandwidth (Savino, et al, 1972). Variations in the base by factors of 1.5-2.0 or greater and return to base over a 24 hour period also suggest that the variations are in the ground noise rather than the system.

C. LONG-TERM NOISE TRENDS (17-25 AND 30-40 SECOND BANDS)

Intermediate band RMS noise for the 17-25 and 30-40 second bands taken from samples recorded during 1971 is shown in Figure III-2. Open symbols on the figure represent the 17-25 second RMS ground noise amplitudes and the closed symbols show the 30-40 second noise for each Julian Day sampled. Most of the observations here represent an average of two samples taken about twelve hours apart during sequential 24 hour periods. The data are shown primarily for indication of sampling times that are included in a summary discussion later. No long-term trends can be suggested from Figure III-2. The 1971 data show characteristics representative of the noise in these bands observed over longer periods. In particular, the 17-25 second band amplitudes are not always larger than 30-40 second amplitudes and the two bands do not necessarily increase or decrease in unison.

Noise samples for 1972 (one per day) are more continuous for each location compared to 1971. The RMS noise in the two bands for 1972 samples are shown in Figures III-3 (KON), III-4 (TLO), III-5 (OGD), III-6 (CHG and FBK), III-7 (KIP and CTA), and III-8 (EIL). These represent the same samples shown in Figure III-1 for the 20-40 second band. Closed and open symbols are again used for the 17-25 or 30-40 second noise as above.

In contrast to the 20-40 second band data (Figure III-1), these data show characteristics of the noise structure which might not be immediately evident in the broader band. For instance, the simultaneous noise event (days 017-020) is both a long and a shorter period event and both bands show an increase. However, days 009-013 show another simultaneous noise event where the shorter period increase (17-25 second band) has no particular representation at 30-40 seconds.

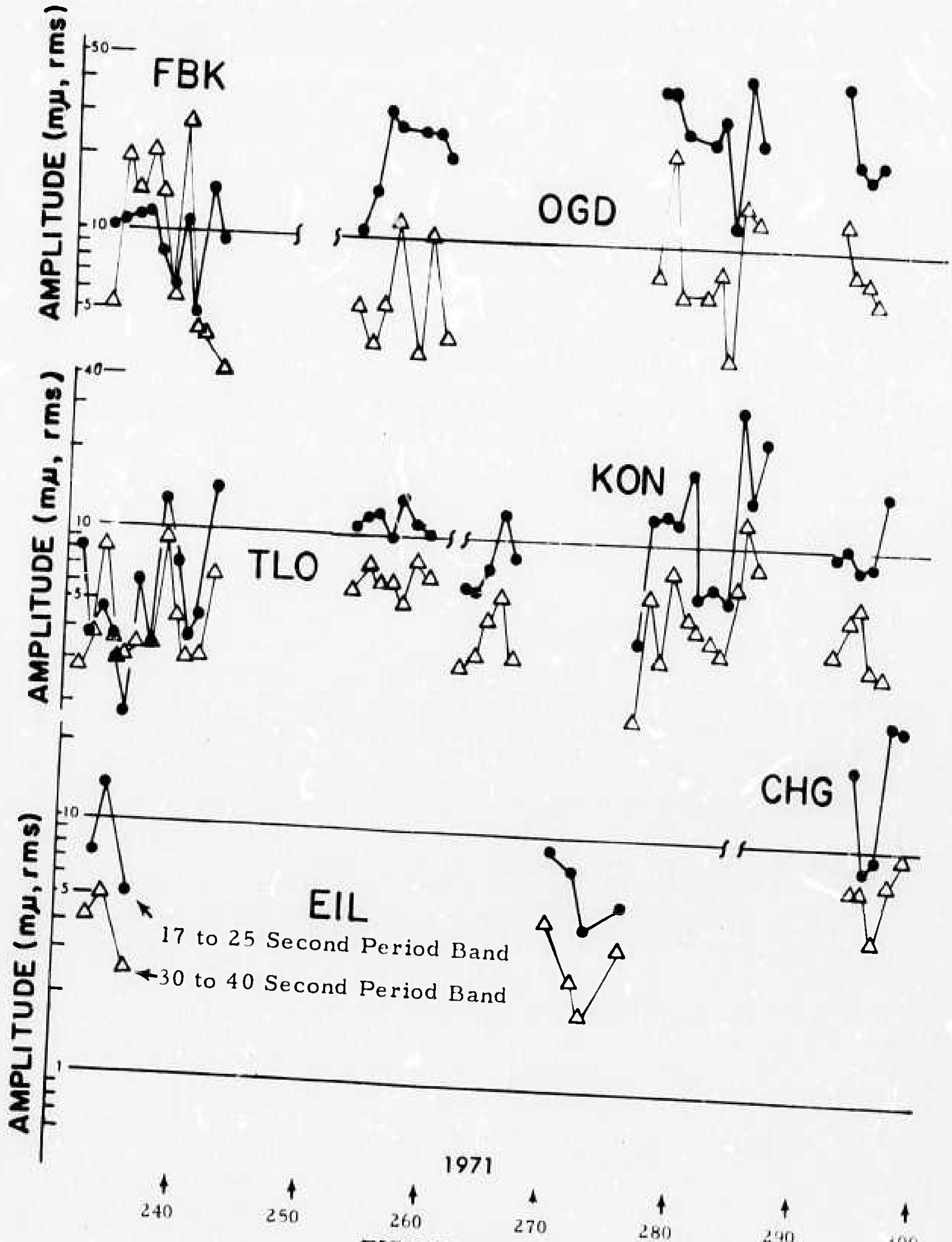


FIGURE III-2

VERTICAL GROUND MOTION (mμ, RMS) IN ONE-HOUR NOISE SAMPLES AT VLPE LOCATIONS (1971)

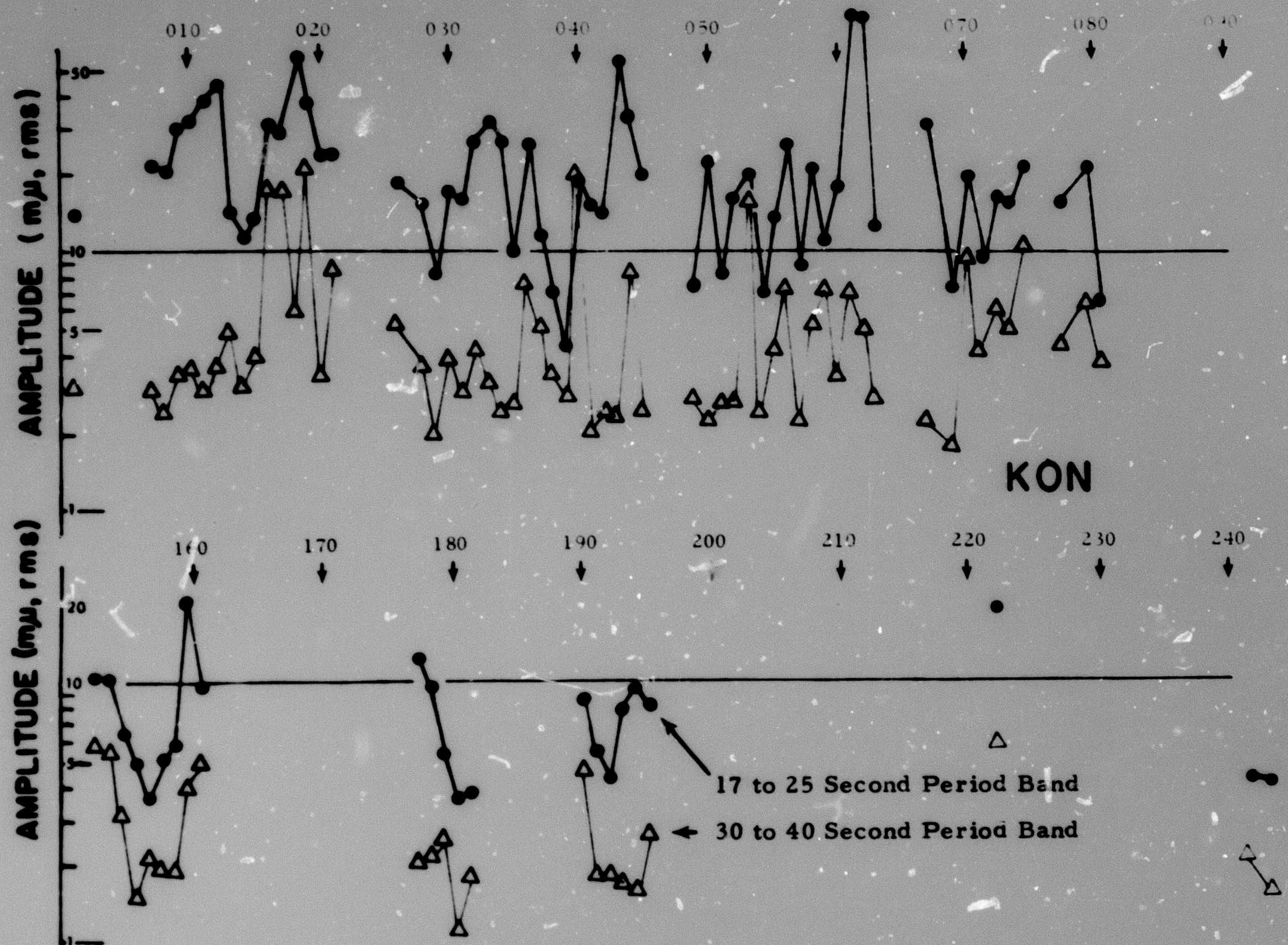


FIGURE III-3

VERTICAL GROUND MOTION (mμ, RMS) IN ONE-HOUR NOISE SAMPLES AT KONGSBERG, NORWAY (1972).

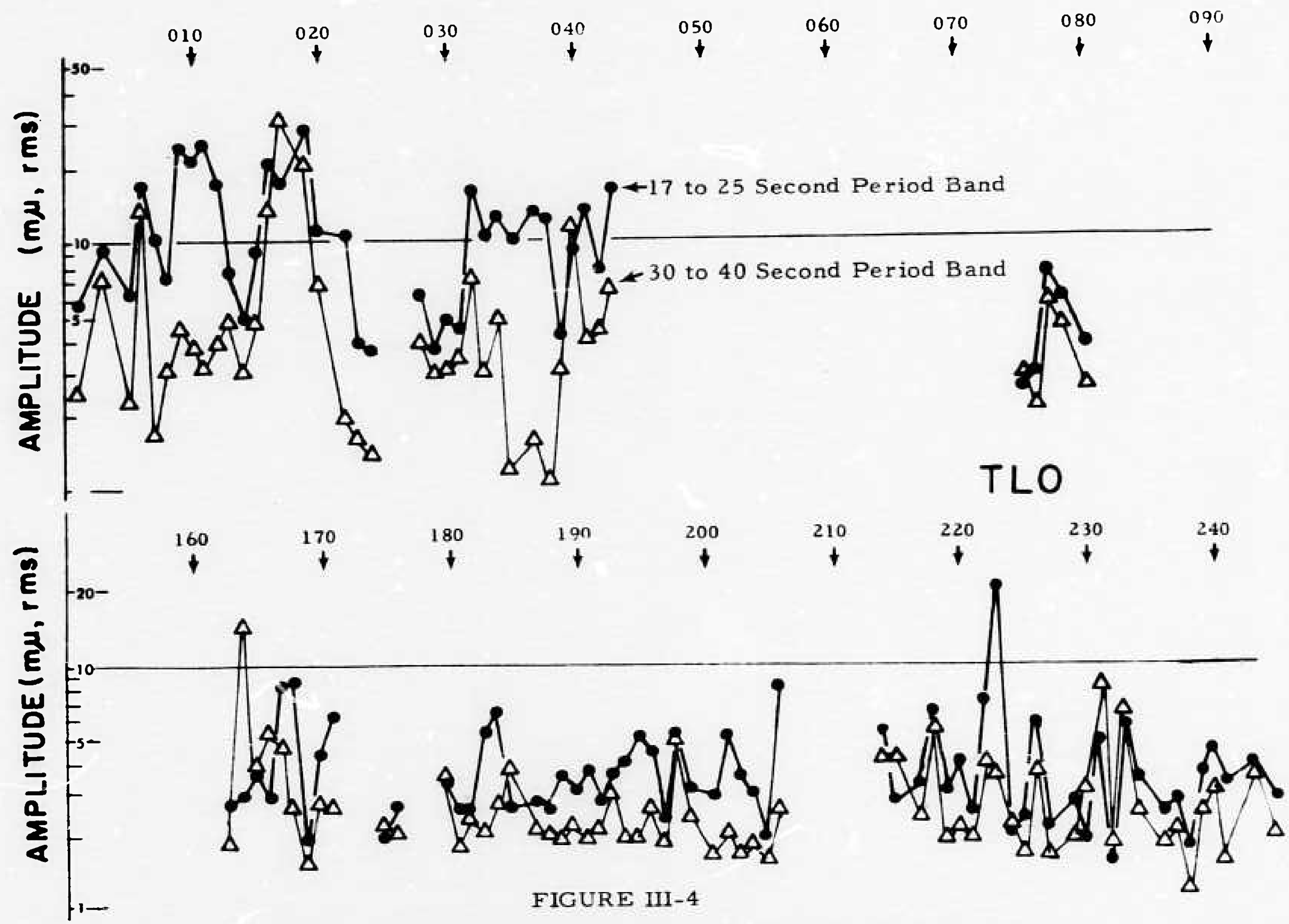


FIGURE III-4

VERTICAL GROUND MOTION (mμ, RMS) IN ONE-HOUR NOISE SAMPLES AT TOLEDO, SPAIN (1972).

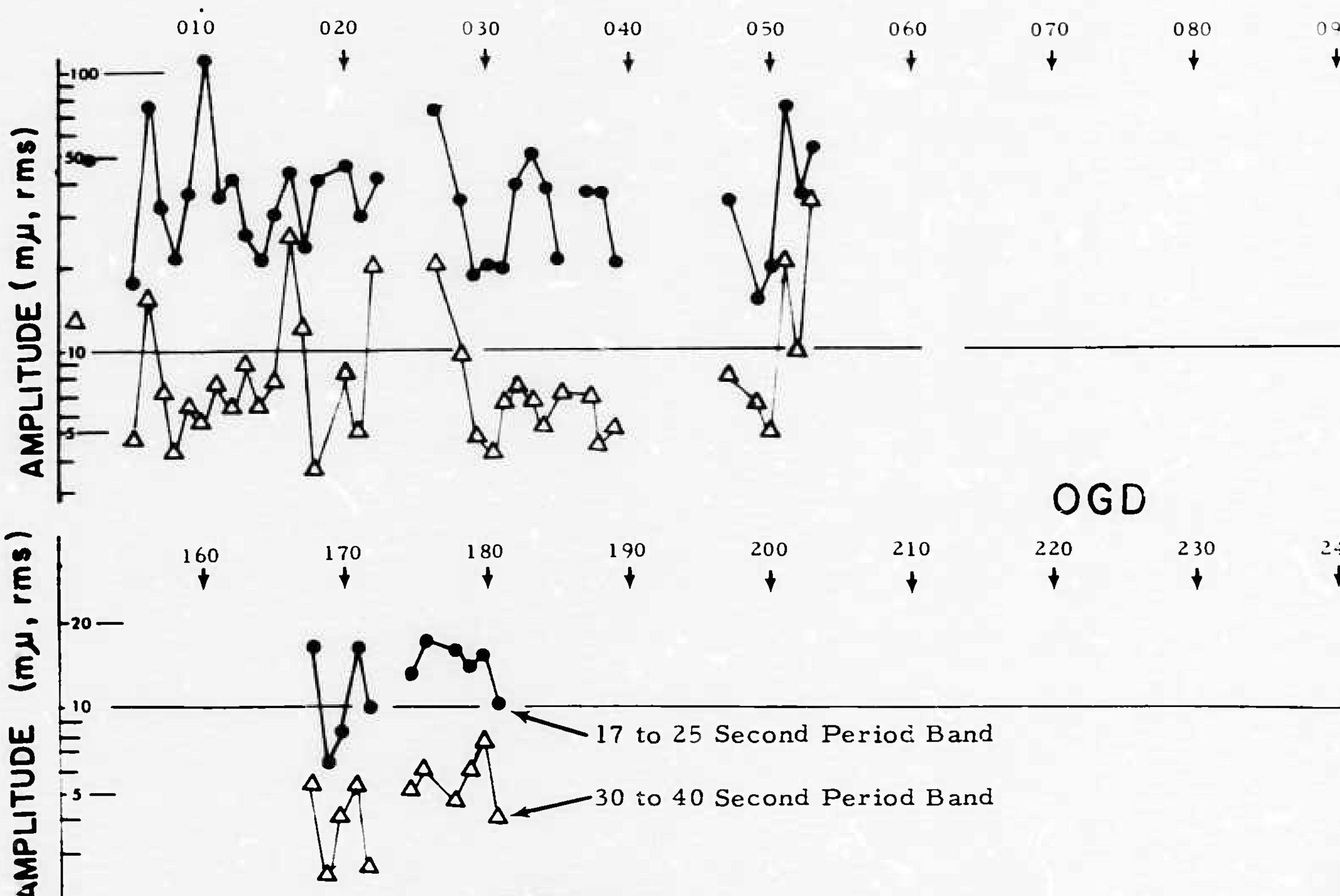


FIGURE III-5

VERTICAL GROUND MOTION (mμ, RMS) IN ONE-HOUR NOISE SAMPLES AT OGDENSBURG, NEW JERSEY (1972).

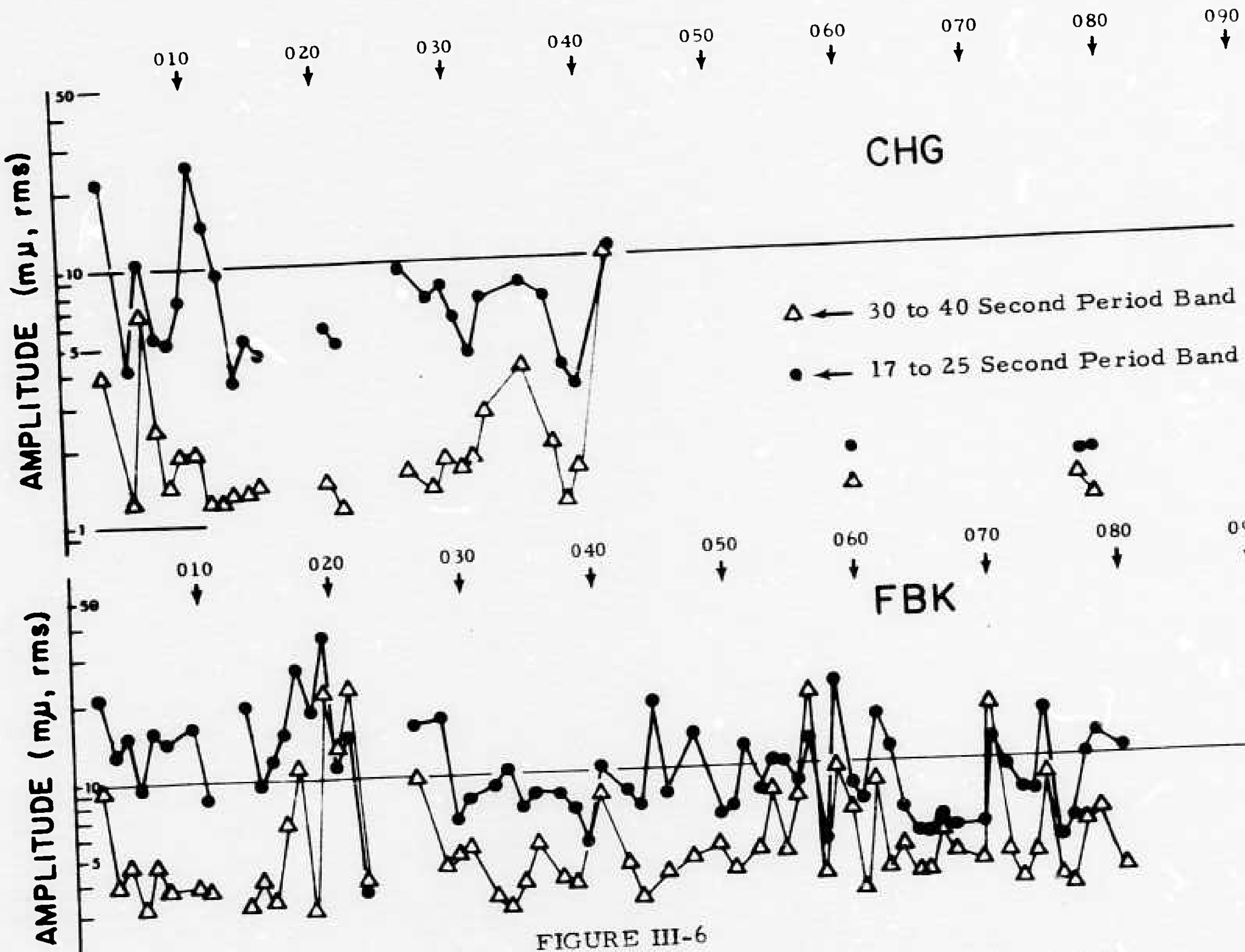


FIGURE III-6

VERTICAL GROUND MOTION (mμ, RMS) IN ONE-HOUR NOISE SAMPLES AT CHIANG MAI, THAILAND AND FAIRBANKS, ALASKA (1972).

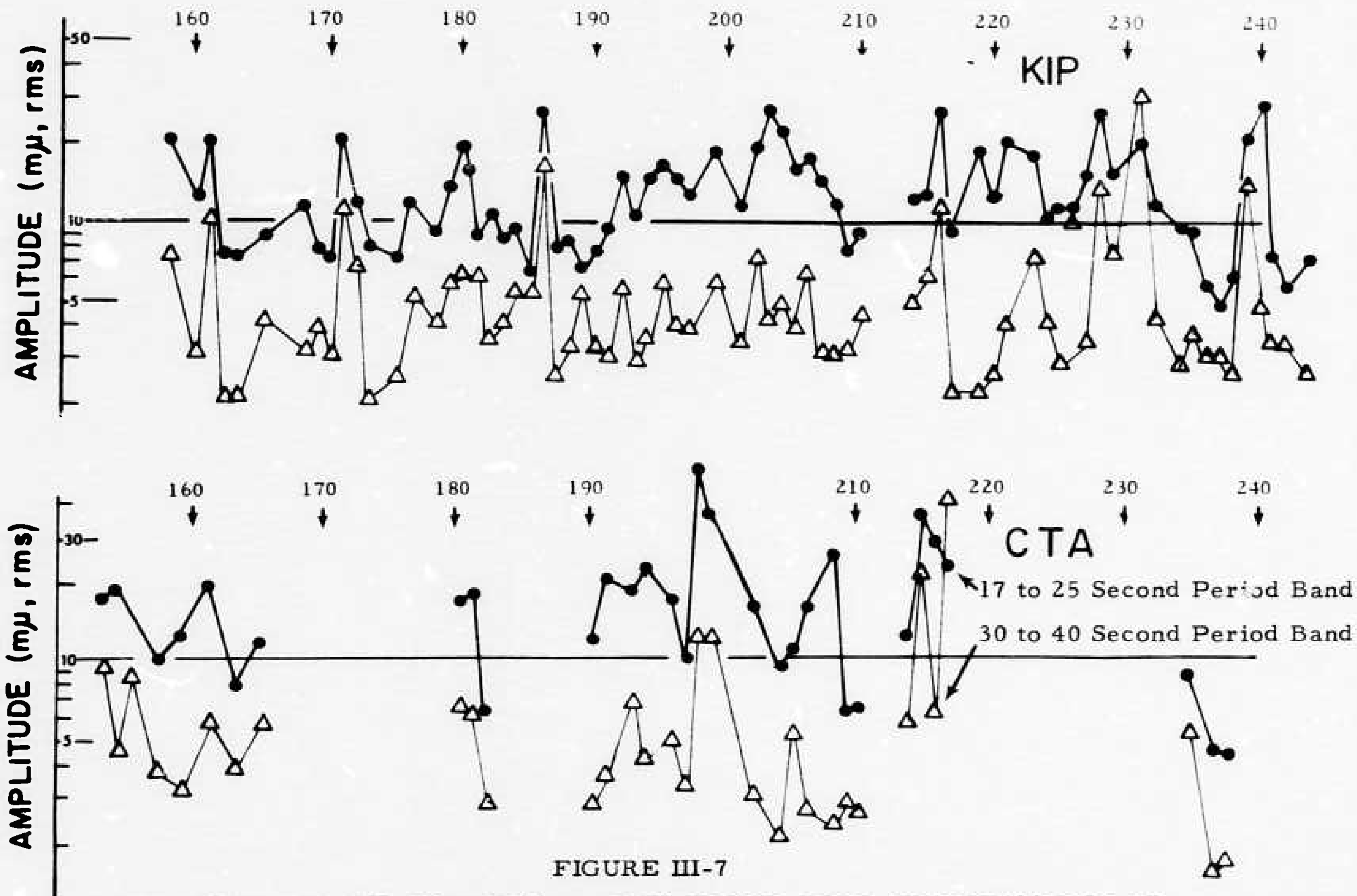


FIGURE III-7

VERTICAL GROUND MOTION ($m\mu$, RMS) IN ONE-HOUR NOISE SAMPLES AT KIPAPA, HAWAII AND CHARTERS TOWERS, AUSTRALIA (1972)

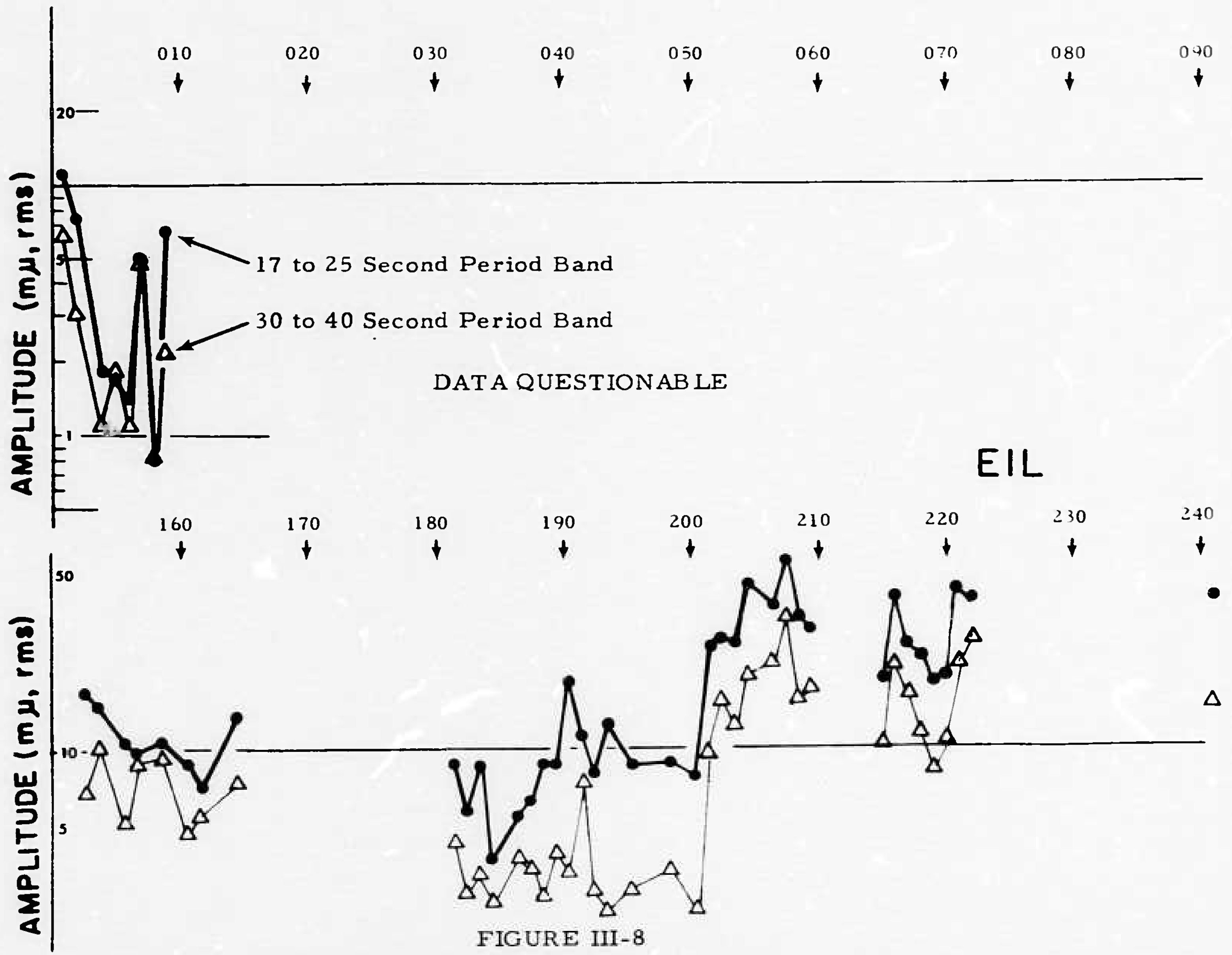


FIGURE III-8

VERTICAL GROUND MOTION ($m\mu$, RMS) IN ONE-HOUR NOISE SAMPLES AT EILAT, ISRAEL (1972)

Noting that all of the two-band figures (III-2 through III-8) have a logarithmic vertical axis, the variations of 30-40 second RMS amplitudes are obviously less variable than 17-25 second amplitudes, and are also two to four times lower on the average. The base level noted in the 20-40 second band appears to be more strongly a function of RMS amplitudes at 30-40 second periods, with the possible exception of TLO, than at shorter periods. Long term trends are not quite as clearly separated in the two bands, but data at FBK, KON, OGD, and KIP show greater decrease in RMS amplitudes from early to mid 1972 in the 17-25 second band as compared to the 30-40 second amplitudes.

D. LONG-TERM NARROW BAND AVERAGE NOISE AND NARROW BAND NOISE VARIABILITY

Average narrow band RMS ground noise amplitudes for all samples shown in Figures III-1 through III-8 (including the two per day samples in 1971) are shown in Figures III-9 through III-12. The total number of one-hour samples at each location for this summary is given in Table II-1. Heavy black dots are the average of the RMS amplitudes in each figure and show the sixteen 4-millihertz bands making up the bandwidth equivalent of 13.5-62.5 seconds. One standard deviation of the data in each narrow band is represented by the vertical hatchures.

Common features in the broad-band noise structures are readily identified in the figures, such as the low RMS amplitude levels around 30-40 seconds compared to shorter and longer periods, and low variability of amplitudes coincident with low average amplitudes. With two exceptions (KON and FBK), the RMS noise amplitudes are approximately the same at about 60 second periods as those near 15-18 second periods. The differences of average amplitudes in the broad band shown are generally a factor of three to four, with a maximum factor of about five (CTA) and a minimum of about three (KIP).

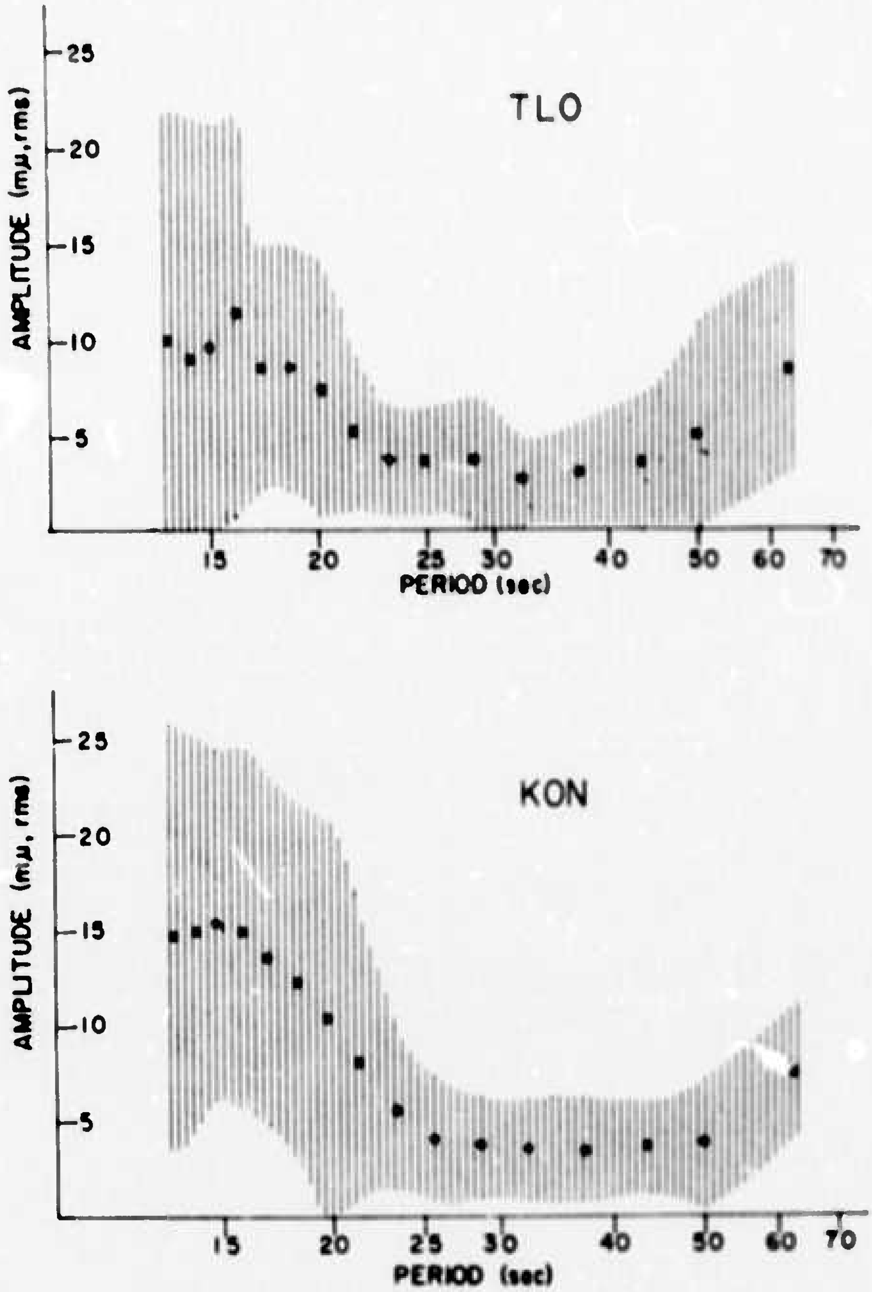


FIGURE III-9

BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT TOLEDO, SPAIN (TLO) AND KONGSBERG, NORWAY (KON). SOLID CIRCLES ARE MEAN VALUES OF NARROW-BAND RMS AMPLITUDES IN MILLIMICRONS, VERTICAL HATCHURES REPRESENT ONE STANDARD DEVIATION OF THE AMPLITUDES ABOUT THE MEANS

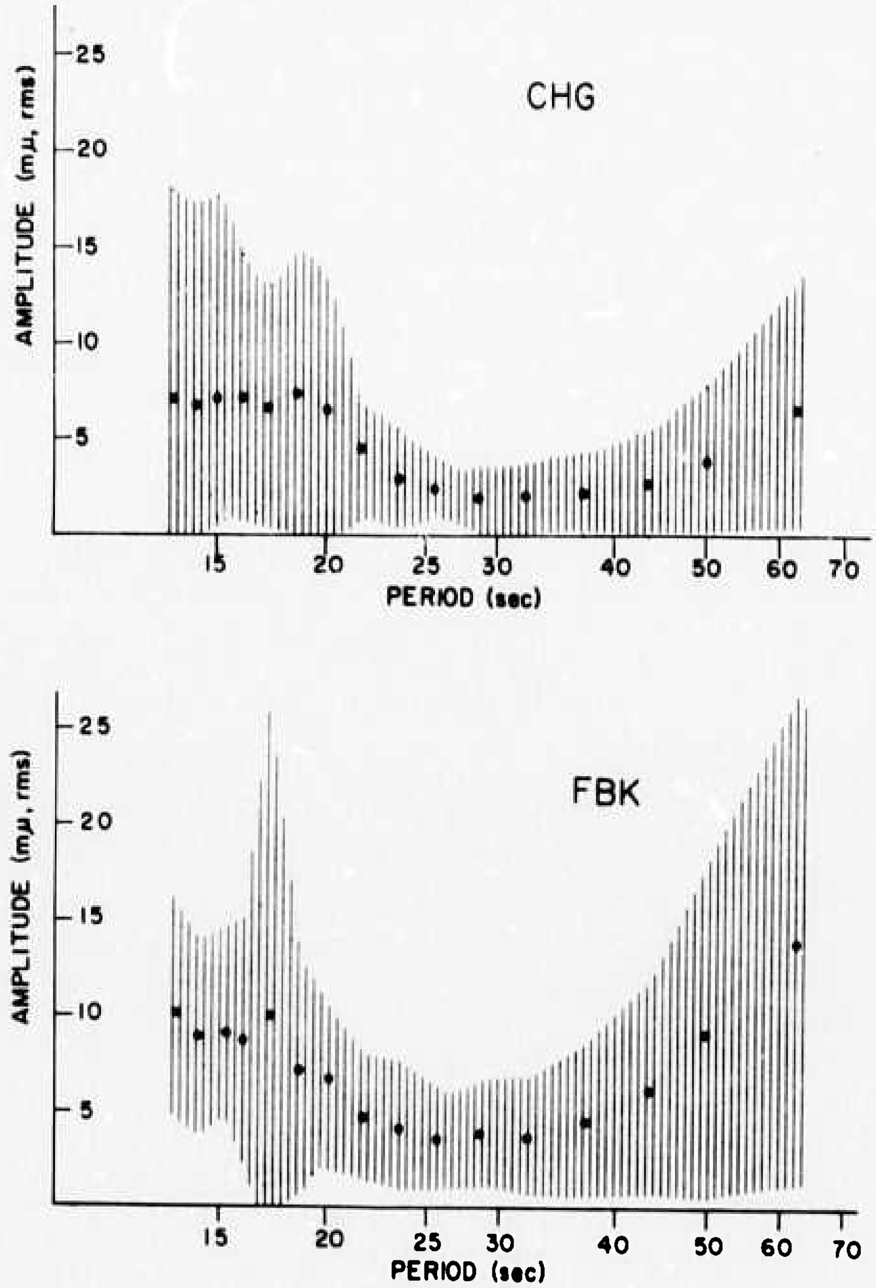
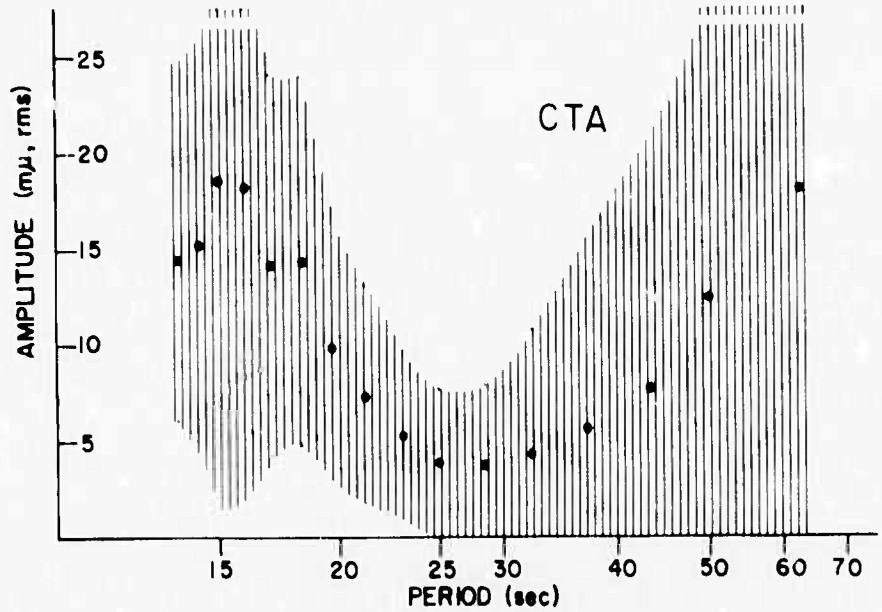


FIGURE III-10

BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT CHIANG MAI, THAILAND (CHG) AND FAIRBANKS, ALASKA (FBK). SOLID CIRCLES ARE MEAN VALUES OF NARROW-BAND RMS AMPLITUDES IN MILLIMICRONS, VERTICAL HATCHURES REPRESENT ONE STANDARD DEVIATION OF THE AMPLITUDES ABOUT THE MEANS



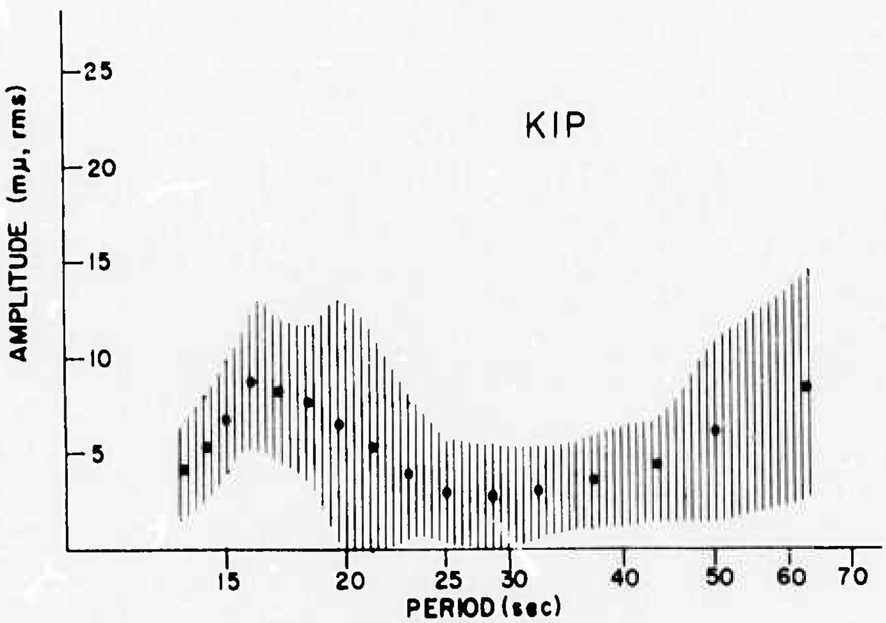


FIGURE III-11

BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT CHARTERS TOWERS, AUSTRALIA (CTA) AND KIPAPA, HAWAII (KIP). SOLID CIRCLES ARE MEAN VALUES OF NARROW-BAND RMS AMPLITUDES IN MILLIMICRONS, VERTICAL HATCHURES REPRESENT ONE STANDARD DEVIATION OF THE AMPLITUDES ABOUT THE MEANS

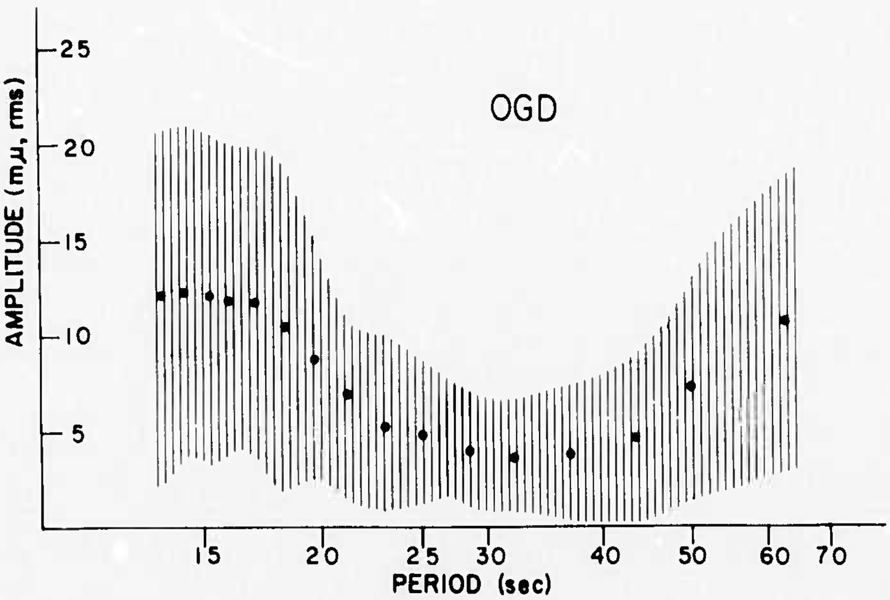


FIGURE III-12

BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT OGDENSBURG, NEW JERSEY (OGD). SOLID CIRCLES ARE MEAN VALUES OF NARROW-BAND RMS AMPLITUDES IN MILLIMICRONS, VERTICAL HATCHURES REPRESENT ONE STANDARD DEVIATION OF THE AMPLITUDES ABOUT THE MEANS

Minimum average noise in any narrow band shown in the figures ranges from 2.1 mμ RMS (CHG) to 3.6 mμ RMS (OGD). Maximum average noise levels cover a wider range, including 18.2 mμ RMS (CTA) and 8.4 mμ RMS (KIP).

The bandwidth of the noise minimum shown in these data is considerably wider than that suggested in the cited publications when identified as a "30-40 second low". The bandwidth is apparently location-dependent in a long term sense. If the bandwidth is defined as including only those narrow bands in which the average RMS amplitudes are no greater than 3 dB above the minimum, the low noise 'minimums' or 'windows' are approximately as given in Table III-1.

Narrow band RMS amplitudes are not normally distributed about the mean values over much of the bandwidth. This characteristic is suggested in the figures showing intermediate band RMS noise levels, particularly in Figure III-1, where the base level of noise persists for relatively long periods of time with occasional days of high RMS noise distributed throughout the period. In fact, high RMS means are accompanied by high standard deviations (and vice-versa) suggesting the two statistics are not independent. A survey of the noise structure by amplitude trends is presented to show low variability in the low amplitude bandwidth, and to suggest the presence of another "psuedo-stable" minimum within the bandwidth considered.

Assuming that the condition of low variability of RMS amplitudes is one criterion for 'stability' of the minimums, low variability (and stability) is evident in parts of the bandwidth outside the 25-50 second region. Average narrow band RMS amplitudes are observed to decrease or to remain approximately constant at wave periods shorter than the microseismic peak (about 16-18 seconds). The variabilities of RMS amplitudes show a very striking decrease in the shorter period data at three locations (FBK, KIP, CTA), and certain time periods show a similar trend at four other locations. Noise data for 1971 at KON, TLO,

TABLE III-1

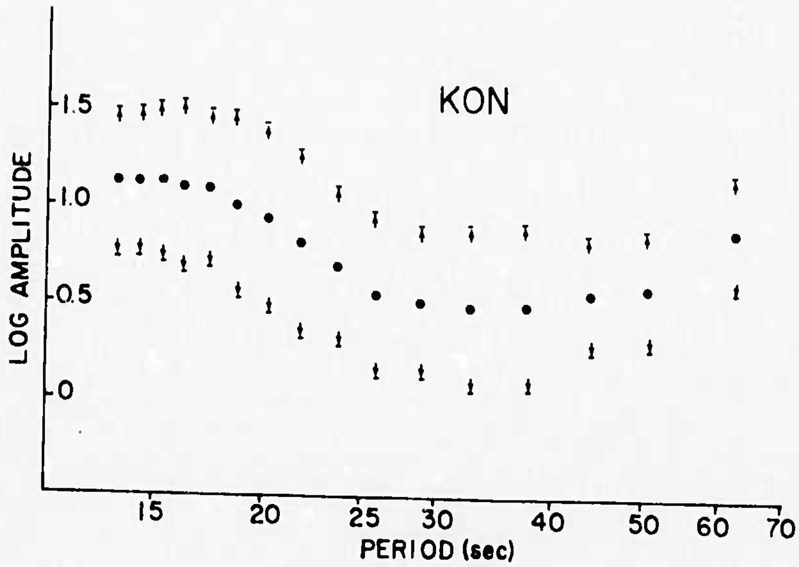
BANDWIDTH OF LONG-PERIOD NOISE MINIMUM AT VLPE LOCATIONS
(LIMITS: AVERAGE NARROW BAND RMS NOISE AMPLITUDES
NO GREATER THAN 3 dB ABOVE AVERAGE FOR
LOWEST NARROW BAND)

Station	Shortest Period + 3 dB limit (seconds)	Longest Period + 3 dB limit (seconds)
CTA	23	37
CHG	25	44
FBK	21	37
TLO	23	44
KON	25	50
OGD	25	44
KIP	21	32

and OGD were summarized early in 1972 (Texas Instruments Special Report No. 8) for a shorter sampling time. That study also showed a distinct decrease in RMS amplitude variability at wave periods less than the microseismic peak. Data from FBK during 1971 show about the same decrease as shown for the 1971-1972 summary, and the limited CHG data for 1971 also show a decrease. There are also suggestions of 5-10 day periods of low variability in most of the intermediate band figures.

A decrease in average ground noise amplitudes at periods less than the 16-18 second peak was indicated by Brune and Oliver (1959), and some VLPE data (Savino, et al, 1972) show a minimum in this trend at about 11-12 seconds period before ground noise amplitudes rise again toward a 6 to 8 second microseismic peak. This band of wave periods may be of importance in detection of body waves (or surface waves at close distances), and the presence of a minimum can be significant. The suggestion given here of a corresponding decrease in variability of amplitudes, even though location and time dependent, leads to describing this minimum as "psuedo-stable" and suggesting the potential importance to seismic signal detection.

In contrast to the RMS amplitudes themselves, logarithms of the RMS amplitudes approximate a normal distribution about the mean of logarithms in each narrow band. Standard deviation of the logarithms of RMS amplitudes (base 10) are approximately constant across the total bandwidth at most stations, or they show rather smooth trends of decrease or increase. These data are shown in Figures III-13 through III-16 for the total set of observations, with the mean logarithm of RMS amplitudes plotted as a solid circle and the .90 confidence limits (for logarithms of RMS amplitudes in the narrow band) by a short horizontal bar and arrow. A comparison of the distribution of RMS amplitude and log amplitude distributions are shown in Figure III-17 for two narrow bands of the Chiang Mai noise observations. Only the shape of the normal curve is shown for comparing the observed data with this model in this figure.



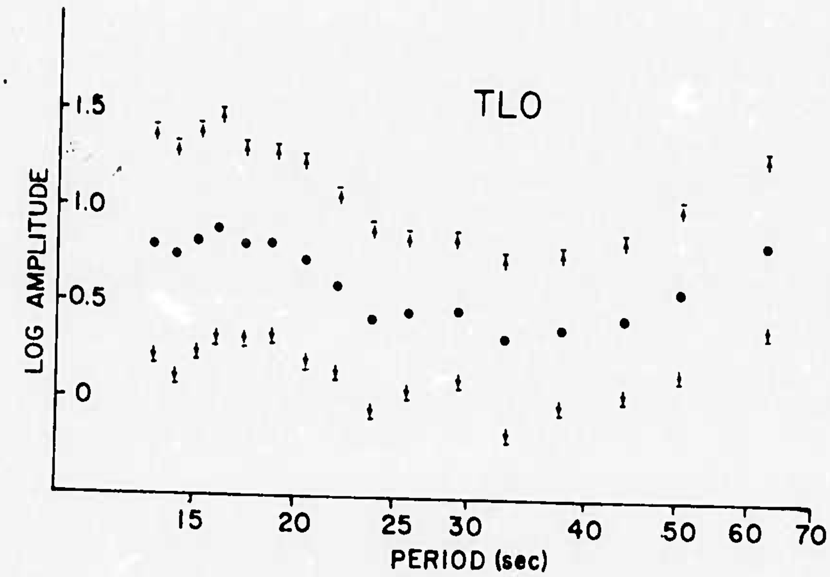


FIGURE III-13

LOGARITHMIC DISTRIBUTIONS OF BROAD-BAND VERTICAL EARTH NOISE STRUCTURES AT KONSBERG, NORWAY (KON) AND TOLDEO, SPAIN (TLO). SOLID CIRCLES ARE THE MEAN VALUE OF THE BASE 10 LOGARITHMS OF RMS AMPLITUDES (IN MILLI-MICRONS), ARROWS INDICATE .90 CONFIDENCE LIMITS FOR THE LOG AMPLITUDE DISTRIBUTION IN EACH NARROW BAND

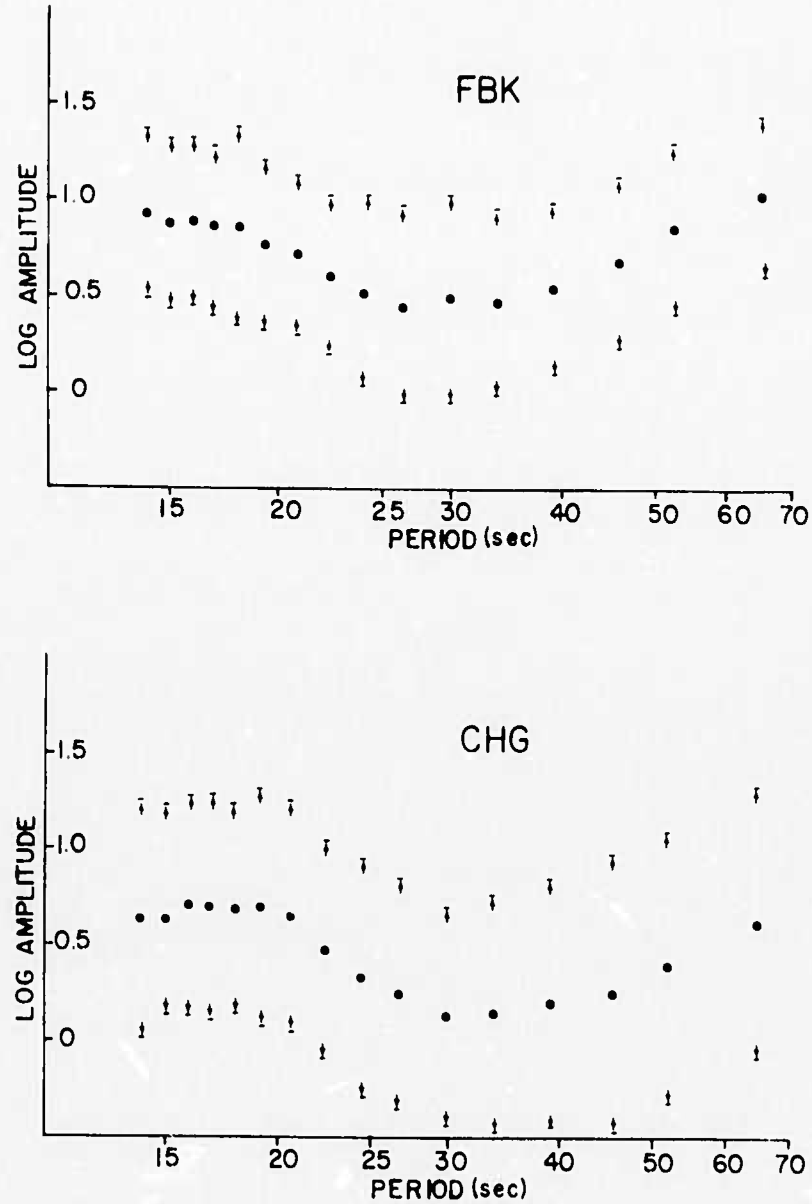


FIGURE III-14

LOGARITHMIC DISTRIBUTIONS OF BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT FAIRBANKS, ALASKA (FBK) AND CHIANG MAI, THAILAND (CHG). SOLID CIRCLES ARE THE MEAN VALUES OF THE BASE 10 LOGARITHMS OF RMS AMPLITUDES (IN MILLIMICRONS), ARROWS INDICATE .90 CONFIDENCE LIMITS FOR THE LOG AMPLITUDE DISTRIBUTION IN EACH NARROW BAND

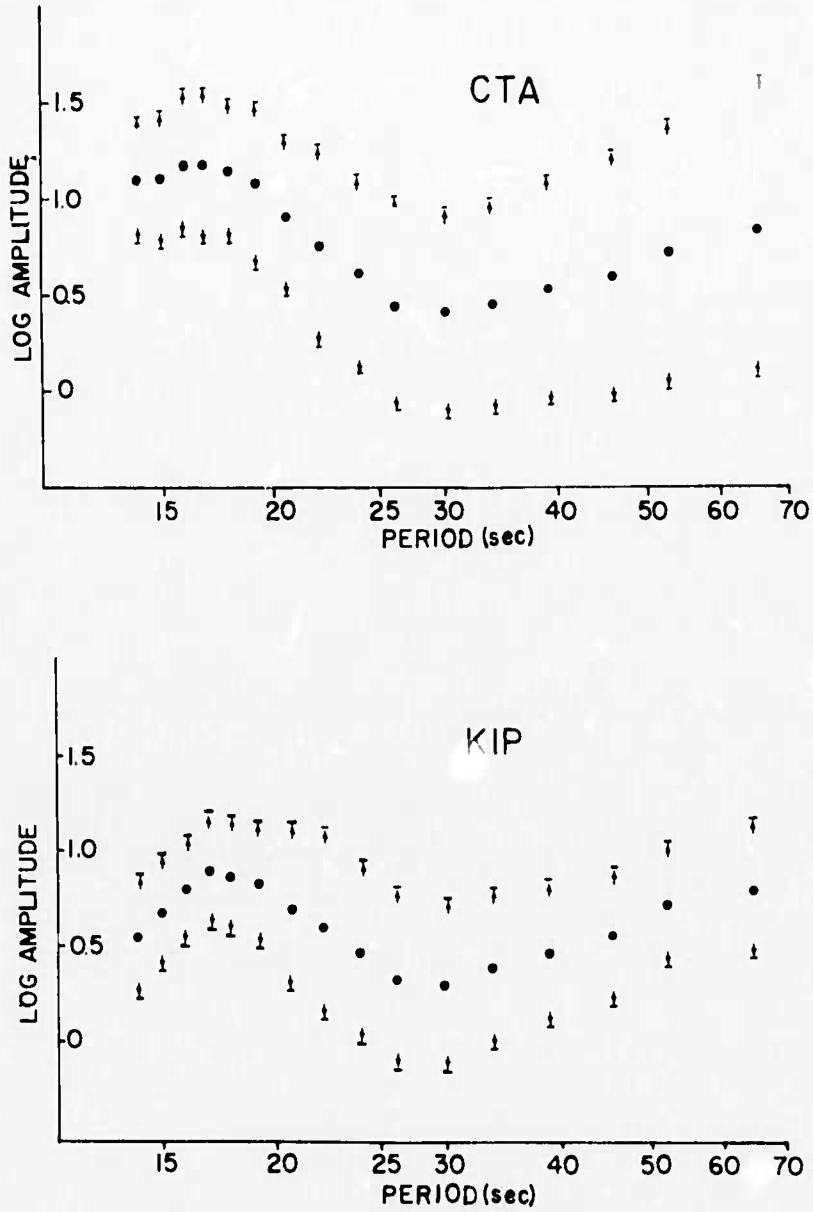


FIGURE III-15

LOGARITHMIC DISTRIBUTIONS OF BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT CHARTERS TOWERS, AUSTRALIA (CTA) AND KIPAPA, HAWAII (KIP). SOLID CIRCLES ARE THE MEAN VALUES OF THE BASE 10 LOGARITHMS OF RMS AMPLITUDES (IN MILLIMICRONS), ARROWS INDICATE .90 CONFIDENCE LIMITS FOR THE LOG AMPLITUDE DISTRIBUTION IN EACH NARROW BAND

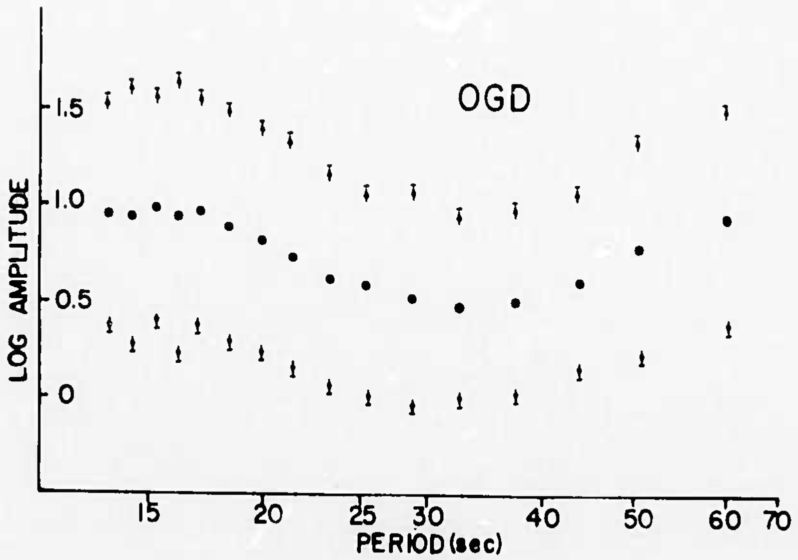


FIGURE III-16

LOGARITHMIC DISTRIBUTIONS OF BROAD-BAND VERTICAL EARTH NOISE STRUCTURE AT OGDENSBURG, NEW JERSEY (OGD). SOLID CIRCLES ARE THE MEAN VALUES OF THE BASE 10 LOGARITHMS OF RMS AMPLITUDES (IN MILLIMICRONS). ARROWS INDICATE .90 CONFIDENCE LIMITS FOR THE LOG AMPLITUDE DISTRIBUTION IN EACH NARROW BAND

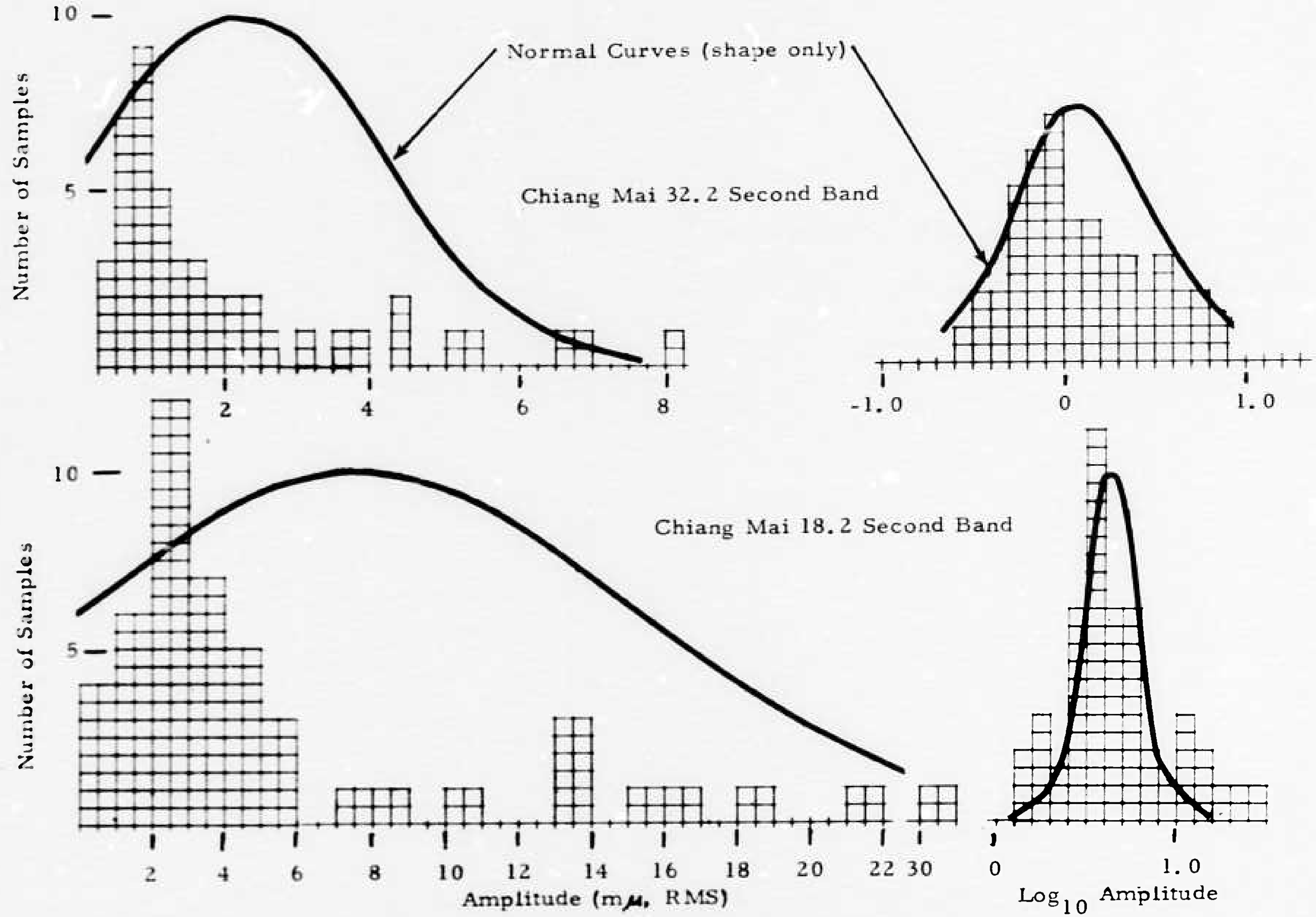


FIGURE III-17. DISTRIBUTION OF AMPLITUDE AND LOG AMPLITUDE NOISE SAMPLES AT CHIANG MAI, THAILAND

The appearance of extreme amplitude changes across the total bandwidth are of course subdued by taking logarithms, but a more accurate representation of the amplitude distributions is obtained. For purposes of modeling combined signal and noise characteristics (as in network detection capabilities), logarithms of signal (such as in estimation of M_s) and logarithms of noise (as above) have the useful characteristic of similarity in dimension.

E. INTRABAND NOISE CORRECTION

Intraband coefficients of linear correlation for the RMS ground noise amplitude observations and base 10 logarithms of the RMS amplitudes are shown in Tables III-2 through III-9. If these data are interpreted to mean that scatter in amplitudes about the means in two narrow bands would be reduced by a percentage approximately equal to the square of the correlation coefficient using a least squares linear prediction of one band's amplitude from the other, then the RMS ground noise amplitudes show very low correlation throughout the bandwidth. Strong correlation (greater than .90) is usually evident only in the immediate neighborhood of any of the bands, but moderate correlation (.70 to .89) may exhibit a broader bandwidth of correlation of intraband amplitude changes. The .70 correlation level is contoured on the tables.

With the exception of KIP, CTA, and CHG, the amplitude correlation .70 level is essentially restricted to one or two narrow bands of bandwidth. At KIP, the .70 correlation level is somewhat broader at long periods (above 30 seconds). Linear correlations of amplitude changes at CTA are moderate to strong above 25 second and below 20 second periods. CHG shows the broadest pattern of correlation, with a moderate level of linear amplitude change correlation over much of the bandwidth below 35 second periods.

Table III-9, which shows the linear correlation coefficient for EIL, is representative of the reason for not examining the data from the location in any detail. According to the table, essentially one-to-one amplitude

Period (seconds)	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5
62.5	.58	.59	.65	.51	.55	.48	.39	.41	.79	.56	.66	.75	.83	.89	.94	1.00
50.0	.63	.60	.67	.54	.56	.55	.52	.59	.63	.70	.78	.85	.88	.94		.96
43.5	.66	.62	.68	.64	.60	.51	.49	.55	.67	.75	.87	.90	.97		.94	.92
37.0	.68	.64	.70	.64	.67	.57	.54	.60	.73	.79	.90	.92		.96	.91	.90
32.2	.70	.68	.73	.63	.65	.61	.61	.64	.80	.88	.96		.95	.93	.89	.87
28.6	.78	.73	.76	.71	.70	.63	.66	.73	.87	.92		.94	.92	.87	.82	.81
25.6	.77	.74	.76	.74	.74	.66	.64	.79	.91		.92	.85	.84	.75	.73	.70
23.3	.74	.72	.73	.67	.72	.69	.73	.84		.85	.84	.72	.71	.61	.58	.54
21.3	.71	.65	.67	.70	.73	.79	.88		.86	.71	.73	.63	.61	.52	.52	.51
19.6	.65	.62	.65	.61	.75	.91		.87	.77	.68	.70	.61	.56	.49	.49	.47
18.2	.70	.68	.74	.74	.87		.89	.75	.69	.65	.63	.57	.55	.50	.49	.46
17.0	.83	.83	.87	.89		.91	.85	.73	.70	.71	.67	.62	.62	.55	.53	.52
16.0	.83	.76	.83		.89	.81	.72	.70	.68	.76	.69	.63	.66	.60	.55	.55
15.1	.97	.96		.88	.81	.72	.64	.61	.57	.67	.65	.66	.65	.62	.62	.61
14.3	.97		.92	.82	.77	.68	.66	.62	.58	.63	.65	.62	.61	.58	.57	.59
13.5	1.00	.94	.88	.77	.73	.65	.68	.69	.62	.68	.64	.67	.66	.65	.64	.64

Ampli de (upper left); Log Amplitude (lower right)

Period (seconds)

TABLE III-2

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT CHIANG MAI, THAILAND

Period (seconds) \ Amplitude	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5
62.5	-.05	-.14	-.13	-.07	-.04	-.03	.09	.21	.28	.45	.68	.79	.87	.89	.96	1.00
50.0	-.09	-.15	-.15	-.10	-.06	-.05	.08	.18	.27	.46	.67	.79	.86	.90		.89
43.5	-.02	-.14	-.13	-.06	-.04	-.04	.12	.22	.33	.49	.67	.80	.89		.87	.87
37.0	.05	-.04	-.03	.06	.05	.04	.22	.40	.55	.68	.81	.91		.86	.80	.83
32.2	.03	.07	.04	.06	.09	.06	.23	.44	.60	.76	.84		.87	.85	.77	.77
28.6	.12	.11	.04	.23	.24	.27	.42	.61	.73	.84		.88	.80	.72	.69	.68
25.6	.18	.12	.19	.31	.29	.31	.48	.69	.85		.90	.83	.73	.62	.60	.58
23.3	.28	.25	.31	.47	.34	.54	.69	.87		.84	.77	.71	.64	.50	.43	.46
21.3	.39	.37	.43	.56	.39	.65	.81		.86	.74	.68	.59	.48	.37	.31	.33
19.6	.42	.45	.55	.64	.52	.86		.85	.77	.69	.58	.44	.38	.30	.25	.26
18.2	.51	.56	.69	.82	.71		.81	.69	.59	.42	.36	.19	.16	.05	.02	.07
17.0	.41	.36	.60	.85		.83	.72	.58	.51	.39	.29	.19	.12	.00	-.07	.01
16.8	.63	.62	.81		.85	.78	.69	.60	.48	.34	.23	.15	.13	-.01	-.09	.01
15.1	.71	.80		.84	.77	.68	.61	.50	.38	.27	.16	.07	.07	-.15	-.15	-.07
14.3	.84		.85	.74	.67	.62	.54	.40	.32	.21	.08	.02	.10	-.06	-.16	-.08
13.5	1.00	.88	.79	.69	.62	.61	.53	.43	.35	.25	.17	.13	.16	.08	-.08	.03

Period (seconds) — Log Amplitude

TABLE III-3

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT FAIRBANKS, ALASKA

Period (seconds) \ Amplitude	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	32.0	43.5	50.0	62.5
62.5	-.08	-.12	-.06	.04	.14	.23	.28	.32	.19	.31	.49	.62	.64	.77	.78	1.00
50.0	-.09	-.10	-.08	.03	.04	.06	.15	.22	.14	.27	.37	.54	.59	.88		.74
43.5	-.01	-.07	-.04	.07	.10	.16	.21	.28	.20	.23	.49	.70	.75		.80	.71
37.0	.12	.05	.10	.24	.29	.36	.48	.62	.51	.54	.87	.94		.85	.76	.66
32.2	.08	.04	.11	.25	.31	.39	.49	.63	.55	.58	.88		.87	.76	.68	.62
28.6	.05	.03	.08	.23	.26	.35	.51	.65	.62	.73		.85	.78	.66	.62	.54
25.6	.06	.00	.05	.18	.22	.32	.55	.70	.79		.84	.75	.67	.52	.49	.41
23.3	.23	.13	.22	.33	.39	.50	.64	.78		.78	.65	.65	.58	.39	.30	.20
21.3	.21	.16	.29	.42	.52	.60	.86		.84	.69	.60	.63	.58	.45	.33	.28
19.6	.23	.23	.37	.52	.68	.75		.85	.74	.55	.48	.50	.47	.33	.23	.22
18.2	.41	.35	.51	.63	.85		.88	.73	.64	.43	.37	.44	.41	.27	.15	.20
17.1	.62	.65	.73	.84		.90	.79	.62	.53	.33	.30	.38	.36	.18	.12	.13
16.0	.84	.87	.91		.91	.84	.72	.56	.45	.26	.24	.32	.30	.14	.03	.04
15.1	.86	.87		.89	.87	.80	.66	.51	.41	.17	.17	.23	.25	.05	-.05	.00
14.3	.90		.92	.88	.81	.72	.57	.45	.38	.15	.16	.21	.23	.04	-.09	-.04
13.5	1.00	.92	.87	.82	.75	.70	.56	.46	.40	.19	.17	.23	.29	.12	-.05	-.01

Period (seconds)

Log Amplitude

TABLE III-4

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT TOLEDO, SPAIN

Amplitude

Period (seconds)	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5
62.5	.12	.13	.17	.16	.12	.19	.19	.34	.51	.59	.46	.45	.69	.74	.79	1.00
50.0	.21	.19	.20	.14	.13	.11	.13	.29	.44	.57	.51	.46	.75	.86		.74
43.5	.10	.06	.12	.05	.05	.06	.08	.29	.41	.58	.51	.49	.88		.78	.72
37.0	.12	.05	.10	.09	.07	.12	.09	.30	.52	.69	.63	.67		.82	.61	.64
32.2	.29	.18	.16	.18	.11	.12	.11	.19	.55	.69	.87		.79	.70	.52	.53
28.6	.27	.21	.22	.23	.19	.23	.25	.33	.63	.77		.82	.71	.69	.58	.52
25.6	.26	.21	.25	.27	.27	.38	.39	.52	.80		.79	.69	.70	.68	.58	.52
23.3	.22	.21	.26	.32	.40	.54	.62	.74		.81	.70	.60	.61	.55	.52	.49
21.3	.13	.21	.24	.43	.54	.72	.89		.81	.63	.49	.31	.38	.40	.40	.40
19.6	.20	.24	.31	.50	.64	.83		.84	.69	.51	.44	.27	.28	.28	.36	.30
18.2	.27	.35	.42	.67	.81		.88	.73	.62	.45	.35	.20	.21	.17	.25	.24
17.0	.32	.47	.56	.81		.86	.80	.64	.52	.39	.33	.17	.13	.15	.27	.18
16.0	.45	.71	.74		.87	.78	.72	.58	.47	.36	.36	.17	.11	.14	.24	.14
15.1	.66	.85		.79	.70	.59	.53	.43	.43	.41	.27	.23	.18	.25	.30	.22
14.3	.74		.81	.73	.60	.51	.48	.39	.37	.31	.34	.21	.09	.12	.23	.13
13.5	1.00	.80	.71	.54	.43	.40	.35	.26	.34	.33	.32	.33	.18	.20	.25	.18

Period (seconds)

Log Amplitude

TABLE III-5

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT KONGSBERG, NORWAY

Amplitude

Period (seconds)	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5
62.5	.39	.43	.40	.41	.31	.17	.21	.31	.33	.27	.36	.42	.45	.47	.49	1.00
50.0	.39	.42	.46	.39	.38	.28	.34	.37	.41	.40	.52	.63	.73	.74		.81
43.5	.28	.36	.48	.40	.32	.24	.33	.31	.39	.25	.49	.67	.90		.86	.76
37.0	.25	.32	.43	.41	.27	.27	.39	.40	.51	.43	.60	.82		.90	.81	.73
32.2	.32	.38	.46	.42	.42	.34	.45	.51	.64	.55	.75		.92	.84	.79	.69
28.6	.42	.43	.52	.59	.47	.48	.66	.74	.81	.81		.90	.84	.79	.75	.65
25.6	.30	.29	.36	.47	.34	.37	.57	.66	.67		.90	.88	.80	.73	.72	.68
23.3	.39	.45	.52	.59	.61	.64	.79	.90		.86	.82	.85	.79	.72	.70	.61
21.3	.42	.46	.46	.57	.60	.64	.80		.90	.84	.83	.81	.77	.75	.72	.65
19.6	.43	.51	.58	.76	.78	.89		.91	.87	.77	.78	.75	.76	.73	.70	.60
18.2	.42	.52	.59	.74	.90		.93	.86	.80	.70	.74	.75	.71	.72	.77	.57
17.0	.47	.62	.67	.78		.93	.91	.83	.79	.73	.76	.76	.77	.76	.75	.69
16.0	.67	.80	.86		.93	.91	.90	.82	.76	.76	.75	.72	.75	.75	.70	.68
15.1	.76	.87		.91	.87	.83	.82	.74	.73	.70	.71	.72	.70	.72	.71	.63
14.3	.90		.92	.91	.85	.82	.79	.74	.70	.70	.72	.72	.70	.73	.74	.68
13.5	1.00	.94	.89	.87	.82	.78	.78	.77	.70	.72	.71	.74	.70	.73	.76	.71

Period (seconds)

Log Amplitude

TABLE III-6

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT OGDENSBURG, NEW JERSEY

Period (seconds)	Amplitude															
62.5	.05	.12	-.12	.00	.18	.03	.07	.08	.33	.54	.77	.66	.77	.82	.95	1.00
50.0	.11	.15	.04	.10	.24	.08	.13	.15	.41	.62	.79	.72	.82	.90		.87
43.5	.25	.29	.13	.24	.33	.22	.15	.22	.54	.74	.85	.88	.92		.83	.79
37.0	.25	.33	.17	.25	.38	.28	.16	.20	.53	.71	.83	.87		.85	.77	.75
32.2	.33	.41	.25	.29	.37	.31	.28	.36	.72	.87	.93		.83	.85	.70	.70
28.6	.30	.33	.23	.20	.31	.26	.30	.36	.71	.89		.84	.81	.80	.74	.72
25.6	.37	.38	.34	.44	.42	.46	.58	.66	.91		.90	.83	.74	.71	.65	.63
23.3	.32	.32	.31	.48	.41	.57	.73	.84		.89	.81	.75	.63	.61	.51	.51
21.3	.18	.21	.34	.54	.40	.69	.94		.86	.78	.64	.56	.48	.42	.34	.34
19.6	.15	.19	.37	.52	.42	.75		.82	.72	.69	.57	.48	.40	.31	.28	.26
18.2	.28	.34	.55	.63	.62		.76	.66	.58	.57	.47	.44	.34	.35	.24	.22
17.0	.31	.37	.54	.66		.67	.57	.50	.43	.51	.43	.41	.39	.34	.34	.35
16.0	.45	.50	.67		.66	.60	.47	.46	.38	.46	.34	.[illegible]4	.33	.28	.20	.17
15.1	.66	.73		.61	.49	.52	.43	.34	.31	.37	.36	.28	.24	.16	.12	.08
14.3	.82		.62	.41	.37	.37	.32	.31	.36	.34	.40	.40	.33	.32	.20	.15
13.5	1.00	.77	.56	.42	.37	.41	.35	.33	.43	.45	.44	.42	.34	.35	.25	.17
	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5

Period (seconds) Log Amplitude

TABLE III-7

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR
GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT KIPAPA, HAWAII

Period (seconds) \ Amplitude	13.5	14.3	15.2	15.9	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5
62.5	.09	.15	.39	.43	.62	.34	.25	.36	.58	.82	.90	.97	.97	.99	.99	1.00
50.0	.13	.19	.43	.48	.05	.38	.29	.37	.58	.81	.89	.98	.99	.99		.96
43.5	.14	.21	.45	.50	.07	.39	.30	.37	.52	.81	.88	.98	.99		.97	.93
37.0	.19	.27	.50	.56	.13	.45	.35	.41	.62	.83	.88	.99		.92	.90	.85
32.2	.18	.25	.47	.54	.18	.50	.38	.49	.69	.90	.93		.93	.83	.83	.75
28.6	.11	.15	.32	.40	.20	.46	.31	.49	.77	.95		.93	.88	.79	.76	.71
25.6	.22	.26	.42	.51	.37	.62	.50	.71	.88		.90	.90	.80	.62	.63	.56
23.3	.31	.35	.47	.55	.52	.71	.61	.83		.89	.76	.78	.71	.55	.53	.49
21.3	.47	.55	.61	.66	.68	.83	.87		.89	.84	.66	.66	.56	.41	.42	.38
19.6	.70	.79	.81	.82	.75	.86		.86	.70	.71	.58	.57	.54	.41	.42	.39
18.2	.58	.70	.79	.83	.86		.87	.84	.74	.77	.65	.66	.59	.42	.41	.36
17.0	.70	.75	.71	.74		.83	.73	.70	.55	.58	.48	.43	.38	.21	.20	.15
15.9	.80	.91	.98		.70	.73	.66	.58	.56	.56	.49	.54	.59	.45	.42	.38
15.2	.80	.91		.91	.61	.60	.58	.44	.38	.38	.34	.39	.47	.39	.36	.32
14.3	.91		.81	.82	.60	.46	.46	.30	.25	.25	.21	.22	.30	.21	.18	.13
13.5	1.00	.83	.65	.65	.54	.33	.42	.26	.20	.25	.21	.17	.21	.15	.15	.14
	13.5	14.3	15.2	15.9	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.0	43.5	50.0	62.5

Period (seconds) — Log Amplitude

TABLE III-8

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AND LOG AMPLITUDE AT CHARTERS TOWERS, AUSTRALIA

Amplitude

Period (seconds)	13.5	14.3	15.1	16.0	17.0	18.2	19.6	21.3	23.3	25.6	28.6	32.2	37.6	43.5	50.0	62.5
62.5	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00
50.0	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	.99	1.00	
43.5	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	.99	.99	.99	1.00		
37.0	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00			
32.2	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00				
28.6	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00					
25.6	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00						
23.3	.99	.99	.99	.99	.99	.99	1.00	.99	1.00							
21.3	.99	.99	.99	1.00	.99	.99	.99	1.00								
19.6	.99	.99	.99	1.00	.99	.99	1.00									
18.2	.99	.99	.99	.99	.99	1.00										
17.0	.99	.99	.99	1.00	1.00											
16.0	.99	.99	1.00	1.00												
15.1	.99	.99	1.00													
14.3	1.00	1.00														
13.5	1.00															

Period (seconds)

DATA QUESTIONABLE

TABLE III-9

INTRABAND LINEAR CORRELATION COEFFICIENTS FOR GROUND NOISE AMPLITUDES AT EILAT, ISRAEL (SYSTEM PRESUMED INACCURATE) change correlation across the entire band is present in the data. In comparison to all of the other locations, and in consideration of the meaning of the coefficient, the data from this location have to be considered at least very questionable. The most probable reason for the coefficients is a systematic change in the system gain, which simply increases or decreases the overall gain without modifying other response characteristics. Station calibration procedures and operations were improved in mid-July, so the intermediate band plots after Day 200 (Figure III-9) may be more accurate than implied by the tabulation of correlation coefficients given here.

The only location showing much difference in the pattern of correlation coefficients for the amplitude and log amplitude data is OGD. A moderate correlation over most of the bandwidth in the log amplitude data is evident as opposed to a less broad linear correlation of amplitude changes. No visual characteristic in the recorded data or the intermediate band data seems to offer an obvious explanation. This observation is simply accepted here as a result of the calculations.which will require further analysis.

SECTION IV
CONCLUSIONS

Presence of a "stable noise minimum" at long periods in the seismic noise field structure is clearly evident at the seven VLPE locations studied. The bandwidth of the minimum is somewhat more location dependent than suggested by earlier reports about its character, with bands ranging from 25-50 seconds period as a maximum to 21-30 seconds period as a minimum and using 3 dB above minimum RMS amplitude to delineate the bandwidth. Stability of the minimums is indicated by low variability of the RMS amplitudes in the bandwidths compared to shorter or longer period motions.

Lowest RMS amplitudes averaged over a minimum of 33 hours of observations range from 2.1 $m\mu$ to 3.6 $m\mu$, and maximums for the same data samples range from 8.4 to 18.2 millimicrons. There appears to be a general minimum level of RMS ground noise at all locations which may be seasonally dependent, and which essentially defines a "floor" in the noise structure over long periods of time. The floor appears to be related more clearly to motions in the wave periods included in the stable minimums than in other more variable parts of the bandwidth.

A psuedo-stable minimum is suggested at periods between microseismic peaks at 6-8 second and 17-19 second wave periods. Observed average RMS amplitudes tend to level off or decrease at periods shorter than 17-19 seconds in the data presented here, and there is a corresponding decrease in variability of the ground motions. This decrease is probably seasonal in nature, but may also be a characteristic of the location itself since the decrease is evident at several locations over time periods as long as about 90 days.

The RMS amplitude observations approximate a lognormal distribution, and the distribution of logarithms of RMS amplitude is relatively constant over the bandwidth. Amplitude changes over the bandwidth show very little linear correlation for either RMS amplitudes or log amplitude comparisons, reflecting the independence of the noise minimums from the stronger microseismic peak activity.

Characteristics of the earth noise structure demonstrated here provide some additional confidence in the stability of the noise minimum identified earlier in the vertical field and show the presence of another relative minimum in the bandwidth. Future work to describe the characteristics of the structure of the horizontal field is underway, and additional observations of the vertical field at both the locations described in this report and at new locations is intended.

SECTION V

REFERENCES

Brune, J. N., and Oliver, J., The seismic noise of the earth's surface, Bull. Seism. Soc. Am., 49, 349-353, 1959.

Capon, J., Investigation of long-period noise at the Large Aperature Seismic Array, J. Geophys. Res., 74, 3182-3194, 1969.

Murphy, A. J., J. Savino, M. W. R. Rynn, G. L. Choy, and K. MacCamy, Observations of long-period (10-100 sec) seismic noise at several worldwide locations, J. Geophys. Res., 77, 5042-5049, 1972.

Oliver, J., A worldwide storm of microseisms with periods of about 27 seconds, Bull. Seism. Soc. Am., 52, 507-517, 1962.

Oliver, J., Additional evidence relating to "A worldwide storm of microseisms with periods of about 27 seconds," Bull. Seism. Soc. Am., 53, 681-685, 1963.

Oliver, J., and R. Page, Concurrent storms of long and ultralong period microseisms, Bull. Seism. Soc. Am., 53, 15-26.

Pomeroy, R. W., G. Hade, J. Savino, and R. Chandler, Preliminary results from high-gain long-poriod electromagnetic seismograph systems, J. Geophys. Res., 74, 3295-3298, 1969.

Savino, J., Long-period earth noise and the detection of and discrimination between earthquakes and underground explosions, ARPA Conference on Nuclear Test Detection, Woods Hole, Mass., Working Paper 1, 20-23, 1970.

Savino, J., and G. Hade, Long-period (15-150 sec) seismic noise observations at the Ogdensburg mine observatory, EOS Trans. Amer. Geophys. Union, 55, 363, 1970.

Savino, J., The nature of long-period (20-130 sec) earth noise and importance of a pronounced noise minimum to detection of seismic events, Ph.D. Thesis, Columbia University, 1971.

Savino, J., L. R. Sykes, R. C. Liebermann, and P. Molnar, Spectra of seismic surface waves (T = 15 - 70 sec) for earthquakes and underground explosions, J. Geophys. Res., 76, 8003-8020, 1971.

Savino, J., K. McCamy, and G. Hade, Structures in earth noise beyond 20 seconds: a window for earthquakes, Bull. Seism. Soc. Am., 62, 141-176, 1972.

Savino, J., and J. M. W. Ryan, Quasi-static loading of the earth by propagating air waves, J. Geophys. Res., 77, 5033-5041, 1972.

Sorrells, G. G. and Z.Der, Long-period seismic noise and atmospheric pressure variations, Tech. Rep. 70-12, 26 p, Geotech Div., Teledyne Ind., Garland, Texas, 1970.

Sorrells, G. G., J. A. McDonald, and E. T. Herrin, Ground motions associated with acoustic waves, Nature, 229, 14-16, 1971.

Texas Instruments, Inc., Documentation of Long Period Experiment Softwave Package, Long Period Array Processing Development, ARPA Order No. 624, Air Force Technical Applications Center contract F33657-69-C-1063, 1971.

Texas Instruments, Inc., Preliminary Network Evaluation Studies, Special Report 8, ARPA Order No. 1714, Air Force Technical Applications Center contract F33657-71-C-083, 1972.